ANALYSIS IN LEAD CONTAMINANTS RESIDENTIAL HOUSEHOLDS IN A MIDWESTERN CITY USING STATISTICAL PROCESS CONTROL

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by

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Lead is an insidious toxic heavy metal with great potential to cause life lasting harm to human life. As of the year 2016, there is a major American city that is currently experiencing a lead related crisis of unknown magnitude. A statistical analysis known as statistical process control was performed in regards to lead levels in an unknown city. The city's location was kept concealed. The results of the analysis concluded that SPC may not be readily applied to environmental concerns. The basic tools of quality can aid in root cause analysis in regards to environmental concerns.

Accepted by: ______________________________, Chair

Ahmad Zargari

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1.1 Chapter One Introduction:

Water is a vital resource that is not only necessary for human life but a requirement of all life on the planet Earth. However, water directly from the earth except for a few circumstances is not fit for human consumption. Therefore, the water requires treatment in order for humans to consume it. Unfortunately, due to choices that were made nearly a century ago, the American water delivery system has failed and has led to lead poisoning. When this system was constructed it was not scientifically proven during that time period that lead was dangerous to human life. When that danger became known. Steps were taken to prevent further lead contamination. Economic costs prevent the government from completely removing the lead lines that lay underneath America. Therefore, scientist have developed numerous corrosion techniques. These techniques do not entirely eliminate lead but reduce the lead to a safe level defined by the EPA.

1.2 Statement of Problem:

As outline in the introduction lead is a serious problem that has wreak havoc on numerous communities. The goal of this thesis was to analyze the lead levels within a Midwestern city in order to determine the cause high lead levels and provide recommendations to correct the problem.

1.3 Significance of Study:

Lead contamination is a serious situation which can lead to adverse health effects. These health effects are insidious and life lasting. There is no known cure to lead poisoning. The effects of lead poisoning are irreversible.

1.4 Objectives:

1. Identify sources of excessive lead levels in residential households within the defined study area. This was done utilizing data provided by the water company within this city. The high lead levels are identified with run charts and the problematic locations are revealed by use of the Pareto Chart.

2. Measure lead in relation and contrast with the maximum threshold lead limit of 15 ppb as defined by the EPA's lead and copper rule of 1992. This process had been carried out by MS Excel table and run charts.

3. Determine if this process was capable. The data was analyzed using statistical process control specifically; capability index to derive a statistical conclusion to determine if this process was under control and capable.

1.5 Assumptions:

Overall this particular city is in compliance. Therefore, detection levels will be analyzed in relation to the maximum EPA established action level of 15 parts per billion. Since the region is in compliance there will only be a few samples that has reached or exceeded this threshold. Therefore, overall lead levels are analyzed. There are no established safe levels for lead.

1.6 Limitations and Geographical Area:

The lead and copper rule only requires 100 sample tested for a population greater than 100,000. The sampling collection method is currently unknown. The sampling collection is dependent on the customer collecting the samples themselves and returning it. It is unknown that the customer followed the sampling procedure accurately which can influence the results. This is

a small sampling pool out of the large population distributed over a large geographic region, that may not truly represent the entire region.

Another limitation was the data. The data was expansive. The data includes copper and lead data from one hundred locations. The data has been collected since 1998. The majority of data was not suitable for statistical analysis. In addition, the data at each individual location were not collected at the same time. Therefore, the data was streamed line for statistical analysis. The data selected for statistical analysis was chosen for completeness.

Due to sensitivities regarding lead contamination. This particular city's location has been concealed. All references to this city including information within the data provided was hidden.

1.7 Definition of Terms:

Action Level: Refers to the level when reached a utility company must take action.

Corrosion Control: Techniques used to inhibit corrosion.

Distribution: Refers to the water network which transfer the water to the customers

Lead: A heavy metal with wide applications, however it is toxic to humans.

Minitab: A statistical software.

Pareto Chart: A chart which visualizes 80% of known problems within a process

Process Capability: C_P determines the capability of a process.

Process Capability Index: C_{PK} determines if the process is centered.

pH: measure of acidic and basic.

PPB: Parts per billion.

Process Capability: A statistical analysis which can determine if a process is or is not capable.

Run Chart: A chart which shows counts over time.

Statistical Process Control: A series of statistical used to control a process or processes.

2.1 Chapter Two Review of Literature:

The literature review was split into three subsections. The first section is a general overview of various heavy metals. The following section is an analysis of two selected case studies regarding lead contamination. The final section is a general overview of the water treatment system. The over purpose of the literature review was to provide background information on the various processes that involve the distribution of water.

The first section of the literature review provided detailed information regarding the following heavy metals; lead copper, arsenic and vanadium. Special emphasis had been placed on lead due to the recent as controversies surrounding that particular heavy metal.

The second section of the literature review is an examination of two cases of lead contamination in the United States. The first example is the Washington D.C incident which occurred at the beginning of the 21^{st} century. The second example is the current, as of 2016, the Flint Michigan lead water crisis. The literature review ignored the political aspects of these controversies as much as possible. Instead the purpose of the case studies within the context of this literature review is to provide a solid scientific understanding of heavy metal contamination.

The third section is a general overview of a typical water treatment system. The term "typical" is used because depending on the water source each water treatment process is slightly altered. Therefore, different water sources require treatment processes. For example, groundwater water sources require that the water would need to be soften before personal use.

2.2 Heavy Metals:

Heavy metals are compounds with high densities; specifically, "heavy metals are naturally occurring elements that have a high atomic weight with a density five times greater

than that of water" (Tchounwou, 2010). Heavy metals are found within the natural environment. Heavy metals can be found in numerous states, either in a pure form or alloyed with other elements. It is also possible for certain heavy metals to be artificially reconstructed. Heavy metals serve an important role in industrial, biological and scientific settings. Heavy metals have useful properties such as high strength, high densities, great electric conductivity, and some heavy metals such as lead are relatively inexpensive. Examples of heavy metals which that are discussed in this literature review are lead, copper, arsenic and vanadium.

Heavy metals in addition to their usefulness in scientific and industrial affairs. Numerous heavy metals serve important biological function. Heavy metals that are of bio-importance are known as trace metals. Trace metals are heavy metals that are important for biological functionality. However, trace metals in excessive quantities are toxic. The toxicity derives from the fact that all heavy metals are toxic to humans. Therefore, the difference between a heavy metal such as lead and a trace metal such as copper can be summarized as the following. Lead in any quantity is dangerous to humans and serves no biological purpose. This is in contrast to copper which in minuscule quantities is important for human functionality. "Heavy metals such as iron, zinc, calcium and magnesium have been reported to be of bio importance to man and their daily medicinal and dietary allowances" (Duruibe, 2007). For example, the purpose of iron within the human body is the creation of a protein known as hemoglobin. Hemoglobin is used to transport oxygen throughout the entire human body.

Even though trace elements are important for human biology. As stated before all heavy metals are toxic. The toxicity of lead, copper, arsenic and vanadium are explained in detailed in the proceeding sections. However, to express the potential adverse effects of heavy metal contamination an example is given using the heavy metal cadmium.

Cadmium is toxic at extremely low levels. “In human’s long term exposure results in renal dysfunction, characterized by tubular proteinuria. High exposure can lead to obstructive lung disease, cadmium pneumonitis, resulting from inhaled dusts and fumes” (Duruibe, 2007).

Cadmium is a heavy metal that is typically used in constructing batteries. Fortunately, cadmium is an occupational hazard rather than hazard found in drinking water or in the natural environment. Cadmium toxicity is primarily obtained from the inhalation of cadmium fumes during and after the manufacturing process.

Heavy metal toxicity can be treated with chelation agents. However, some heavy metal toxicity effects are permanent such as arsenic. Even though the heavy metal toxicity is treated. Many of the effects which were present throughout the toxic event may be permanent such as neurological damage from lead toxicity. The reason why these effects are permanent is unfortunately there is no cure for neurological damage. Hence is why prevention being the key to treating heavy metal toxicity. In the case with lead the damage occurs slowly over several years with children at the most risk. Usually as in the case of lead toxicity by the time the health risks become apparent; it is far too late for any type of treatment to be effective.

2.3 Lead:

Lead is a bluish-white lustrous metal. It is very soft, highly malleable, ductile, and relatively poor conductor of electricity (Water Treatment Solutions, 2016). “Lead is a relatively corrosion-resistant, dense ductile and malleable metal that has been used by human for at least 5,000 years” (Brown, 2010). Lead is somewhat inexpensive compared to other metals. Lead is relatively inexpensive and the metal’s ease of use is the reason for metal’s wide adoption in the past. In addition to the metal's usefulness in industry, the metal has demonstrated some cosmetic

purpose. When lead is used in paint the results are extremely attractive and vibrant colors. Lead based was used for centuries until the toxic side effects of lead were discovered. The use of lead paint was eventually made illegal. With lead based paint outlawed; the primary source of lead contamination in the United States is currently drinking water. Drinking water resulting as the primary source of lead is unknowable to the general population. The flakes and chips of this particular type of paint could be easily eaten by small children. However, lead in water is invisible and much more insidious.

Currently the primary source of lead toxicity in the United States is drinking water. Unfortunately, this aspect is sometimes ignored until a serious crisis occurs. The crises regarding lead are discussed in greater detailed in the case studies section. Never the less even though the United States made great strides due reduce lead toxicity due to lead base paint. Removing lead from drinking water is an extremely complicated matter.

Fortunately, the effects of lead and other heavy metals can be mitigated within the water supply network. This can be done by adding “phosphoric acid, ortho-phosphoric acid, zinc orthophosphate, polyphosphate and silicate, or mixtures of these chemicals” (Mass, 2005). These compounds promote a concept known as scale forming. For example, phosphate is added to a water supply network. The phosphate undergoes a chemical reaction in the water which causes a “scale” to form inside the pipe. This scale forms a layer which prevents the lead from leeching into the water. This scale can also prevent other heavy metals from leeching into the water supply as well. There are numerous tests that can be perform to ensure that proper scale forming has occurred such as stability pH tests. However, adding additional chemicals into the water network carries their problems. When certain types of phosphate are added pH levels are lowered. Certain other types of phosphate dosing require the pH level kept within strict

parameters to promote scale formation. The chemistry is fairly complicated. In general, it is important to conduct trail runs before any permanent changes are made to the water treatment process. There are has several cases such as the Washington D.C lead crisis and the current lead crisis in Flint Michigan were proper tests were not conducted before changes were made to their respective water treatment processes. The failure to conduct pre-emptive test has led to a serious environmental and personal damages.

There are numerous other scale forming additives which can be used such as sodium hex also known as sodium hexmeaphosphate. Each of these forms of corrosion controls has their own advantages and disadvantages. Therefore, it is not simply a matter of choosing the cheapest corrosion control. It is a matter of chosen the best corrosion control for each individual water source. Some water sources by default are not as corrosive as other sources. In that case less corrosion control is needed. In cases that highly corrosive water is used such as the incident in Flint Michigan. Aggressive corrosion control techniques are needed. There are also the economic concerns as well. In many cases the best options are not the most economical. Never the less these values needed to be monitored constantly for any unforeseen consequences.

Lead and other heavy metals such as copper are significantly regulated by the United States federal government. This regulation is policed by the Environmental Protection Agency. Lead and copper specifically are regulated by the lead and copper rule. The purpose of the lead and copper rule is:

> Protect public health by minimizing lead (Pb) cooper (Cu) levels in drinking water, primarily reducing water corrosion. Pb and Cu reenter drinking water mainly from corrosion of Pb and Cu containing plumbing materials (Lead and Copper Rule, 2008).

Under the lead and copper rule the action level of lead is .015 mg/L. The term action level refers to in this case the water company; would be required to take steps to correct the situation. These steps include notifying the customer. The water company are not responsible for any lead related materials on the customers proper. The reason why the water company are not responsible for the lead related materials is there are no lead or copper present in the water when it leaves the treatment facility. Lead and copper in the water distribution network is the result of the pipes within the distribution network and sometimes the customer's plumbing. The case where the lead and copper occurs on the customer's property is difficult for the water company to correct because legally it is the customer's responsibility. The situation is further complicated by just removing the lead branch that the water company is responsible for can increase lead within the distribution network. This is due to the process of galvanizing between the lead branch on the customer side and the new replacement branch on the water company's side.

Lead is a divalent cation, and it binds strongly to sulfhydryl groups on proteins. Of the many organs affect by lead, the most important is the central nervous system (Needleman, 2004). Lead also has the ability to damage the genetic material of cells (Liasi, 2008). In additional there is evidence to support that there could be a genetic susceptibility to lead toxicity (Onalaja, 2000). Lead is known to affect every organ in the body. Lead toxicity is known for causing developmental milestone delays, cognitive disabilities, and aggression. There may be a correlation between lead toxicity and the high crime violence rate which peaked in the 1980s in the United States. The problem with lead toxicity is that these effects are not discovered in children until the kids have not reached their developmental milestones. Unfortunately, if lead toxicity is discovered then; there is nothing that can be done. Lead damage is irreversible. Therefore, purpose vigilant monitoring of lead is conducted by federal, state and local agencies.

The effects of lead are life lasting. Unfortunately, the effects of lead are more serve in children due to their developing bodies.

> Lead exposure in early childhood has been associated with lowered IQ, mental retardation, and decline in academic performance in a dose-response relationship, even at levels below the Centers for Disease Control and Prevention's level of concern. Lead exposure has also been associated with changes in behavior, including inattention and irritability, violence, and attention deficit hyperactivity disorder (Wagner, 2001).

Children are at the most risk of lead contamination. Most lead monitoring programs for this reason focus on protecting children and pregnant women. Lead toxicity is not immediate however. Therefore, when the symptoms of lead toxicity present themselves it is unfortunately there is not much can be done for the child. As indicated by Wagner the effects are lead toxicity of children are life lasting and largely cannot be reverse. Besides the health costs there are economic repercussion of lead toxicity.

> Strikingly, comparisons of lead levels and violent crime over several decades demonstrate near one-to-one relationships. The cumulative evidence regarding the effects of lead poisoning indicates that childhood lead exposure may be a serious impediment toward reaching several education-related goals on the Michigan Dashboard, including third grade reading proficiency, student academic growth, and ACT college readiness. Childhood lead poisoning is 100% preventable, and measures such as lead-based paint abatement are cost-effective. Savings related to reducing childhood lead poisoning include not just medical treatment costs, but savings in expenses related to special education, crime, and economic costs due to decreased productivity. Early prevention of

childhood lead poisoning should therefore be a key component of educational policy and reform (Wagner, 2001).

Even though lead toxicity is a chronic lifelong condition. Excessive lead toxicity can be treated in the same manner as other heavy metal toxicity. “The currently approved clinical intervention method is to give chelating agents, which bind and remove lead from lead-burdened tissues. Studies indicate, however, that there is a lack of safety and efficacy when conventional chelating agents are used” (Gurger, 2000). The chelation method in regards to lead toxicity may not be effective and involves considerable undesirable side effects. This would explain why lead contamination remains a precarious issue. If treatment is readily available, the treatment itself must not be effective. In addition, the damage that lead causes is irreversible. So even if the treatment itself is highly effective; only palliative care.

It is important to note even though the EPA does have an action level for lead. In reality there is no safe biological level for lead. The reality of the current situation is that is not economically feasible to remove lead entirely from water. To remove lead from water completely would entail billions of dollars in cost. For example, the City of Cincinnati in response to the lead crisis in Flint has considered funding the removal of all known lead braches in the city. The low end cost of this project is 82 million dollars. This is one city and Cincinnati had the foresight of banning all lead in the 1920s. This means that the 82 million price tag may be unusually low for a major city.

The effects of lead toxicity do not present itself until later in life. For example, a child exposed to lead since birth will not display not display any of the characteristic effects of lead toxicity until around kindergarten. Typically, the child will miss developmental milestones which will prompt a thorough investigation. In addition, there may be other costs of not

rectifying the situation. Lead toxicity is known to reduce IQ and increase aggression. Even low levels of lead shown that long-term low-level lead exposure in children may also lead to diminished intellectual capacity (Jarup, 2003). Many social science attribute America's high crime rate which peaked in the mid-1980s primarily to higher levels of lead. In the presence older communities which usually are lower income but not necessarily are the areas which usually have both high lead levels and crime. There are steps in the present that can be taken to correct the problem but they are inefficient and will be discussed further in the case study section.

However, in a residential setting there are numerous steps customers themselves to do to alleviate the presence of lead. First if the customer has the financial support to do so they could remove all lead related materials from their property. In addition, because of the effect of galvanization nearby lead branches would need to be removed as well. This can be coordinated with the local water company. However, many people are unaware of this and attempt to unknowingly remove the lead branches themselves. Removing lead branches is very expensive as stated before when the water exits the treatment facility it is free of lead. The lead usually is found on the customer's property. Technically the water treatment facility is not financially responsible for removing lead related materials from customer’s property. The customer can flush their system every morning for about ten minutes before using the water for drinking. The water while it remains motionless overnight allows the lead to concentrate. It is when the water is first drawn in the morning which has the highest lead concentration. Allowing the home interior water system to flush every morning is an effective strategy the customer can take. Finally, the customer could obtain a water filter especially designed to remove lead. Ultimately removing all sources of lead would be the most efficient route to solving the problem of lead

toxicity. However, the financial burden is too great for many to bear. The addition two steps as outline before are inexpensive techniques the customer can used to remove excess lead from their drinking water.

2.4 Copper:

The next heavy metal is copper. Copper unlike lead copper is a trace metal and is needed for biological functions.

> Copper is a reddish metal with a face-centered cubic crystalline structure. It reflects red and orange light and absorbs other frequencies in the visible spectrum, due to its band structure, so it as a nice reddish color (Water Treatment Solutions, 2016).

The usual source of copper for humans is food. However excessive quantities of copper will result in toxicity. Drinking water is the primary source of excess copper. Populations living near sources of copper emissions, such as copper smelters and refineries and workers in these and other industries" (Toxicological Profile for Copper, 2004). Cooper unlike lead has important biological functions. Copper is found in trace amounts in food. However as indicated by the source above excess copper ingestion is primarily from drinking water.

The method in which copper and other heavy metals because damage is copper is, "able to produce reactive oxygen species (ROS) that result in lipid peroxidation, DNA damage, and depletion of cell antioxidant defense systems" (Gurger, 2000). The destruction of the genetic material is another commonality that is shared among heavy metal contaminants. This is another reason why heavy metal contamination can cause irreversible damage. As of current there is no medical procedure or medication that can restore damage DNA. However, unfortunately copper contamination usually does not cause irreversible damage. Unlike other heavy metal

contamination such as lead which causes damage over time. The effects of copper contamination are usually immediate. Copper is a transition metal as a transition metal copper, "A characteristic of transition metals is that they exhibit two or more oxidation states. The oxidized states are Cu^2 and Fe^{3+}, and the reduced states are Cu^+, and Fe^2. This redox capability is what makes them useful in various steps of energy generation. But it is also what allows them to catalyze the generation of damaging ROS" (Brewer, G. J. (2010).

As stated before the primary exposure of excess copper is from drinking water. Like lead the minimum concentration of copper at a water tap occurs when the water has been running for a few minutes and it can be considered fresh from the mains (Lagos, 1999). When dealing with excess heavy metal contamination in water. It is recommended that the customers flush their water by allowing it to run for a few minutes before using it. This is especially important in the morning after the copper has been left in the pipes overnight.

Like lead copper is widely used and has many applications; including biological functions. Copper is mainly known and used for its electrical properties. Biologically like the other trace metal iron; copper is important for carrying oxygen throughout the blood stream and serves numerous other higher biological functions. In addition,

> In humans Cu is necessary for the development of connective tissue, nerve coverings, and bone. Cu also participates in both Fe and energy metabolism. Cu acts as a reductant in the enzymes superoxide dismutase, cytochrome oxidase, lysil oxidase, dopamine hydroxylase, and several other oxidases that reduce molecular oxygen. (Fraga, 2003).

Copper like are all heavy metals is toxic is excessive quantities. Copper is regulated by the Environmental Protection Agency under the lead and copper rule. The EPA's action level for

copper is 1.3 mg/L (Lead and copper, 2008). The negative effects of copper include gastrointestinal distress such as cramps, pain and diarrhea (Hovedya, 2005).

2.5 Arsenic:

The next heavy metal is arsenic.

> Arsenic, a metalloid, occurs naturally. Being the twentieth most abundant element in earth's crust and is a component of more than 245 minerals. The inorganic forms consisting mostly of arsenite and arsenate compounds are toxic to human health (Mazumder, 2008).

There are several other adverse characteristics of arsenic contamination such as, "pigmentation and keratosis are specific lesions characteristic of arsenic toxicity" (Mazumder, 2008). In addition, according to Mazumder these are the following symptoms associated with arsenic toxicity; weakness, headache, burning of the eyes, pain in the abdomen, diarrhea, hemoptysis, dyspnoe and paresthesia.

> The metallic form is brittle, tarnishes and when heated it rapidly oxidizes to arsenic trioxide, which has a garlic odor. The nonmetallic form is less reactive but will dissolved when heated with strong oxidizing acids and alkalis (Water Treatment Solutions, 2016).

In addition to the effects of Arsenic noted in the preceding paragraph. Arsenic is known to cause cancer.

> Arsenic is readily adsorbed from the gastrointestinal tract to the blood. The mechanism through which arsenic causes cancer is not well understood, but data suggest that arsenic

probably causes chromosomal abnormalities, sister chromatid exchanges, and malsegregation of chromosomes that lead to cancer. Anawar, H. (2002)

Arsenic toxicity is usually associated with groundwater sources. Arsenic toxicity is a problem that plagues developing countries. The effects of arsenic toxicity are illuminated below.

Arsenicosis is a chronic illness resulting from drinking water with high levels of As over a long period of time. It is commonly known as As poisoning. Arseniasis means chronic arsenical poisoning also called arsenicalism; the term arsenicism refers to a disease condition caused by slow poisoning with As (Kapaj, 2006).

Furthermore, according to Kapaj author of the Human Health Effects from Chronic Arsenic Poisoning the specific health effects of arsenic includes various cancers such as bladder, lung, skin cancer, neurological effects and effects on IQ.

As in the case of the other heavy metals. In the water system network there are a series of “controls” that can remove Arsenic from the water. The tendency for iron solid surfaces to adsorb arsenic is well-known and has become the basis for several drinking water treatment approaches (Lytle, 2004). The same source suggests that the bind arsenic could be potentially re-released back into the water distribution system. This is can happen because of the bonded arsenic is mechanically distributed, for example road construction. This disturbance can release other heavy metals back in the water supply network and this is the common way the lead is re-released. The scales are disturbed and the lead is released back in the water system.

The problem with arsenic toxicity is not a serve problem in the United States. Drinking water directly from a well even within rural areas has not been phased out. Only residences that live in remote areas do not have access to tap water. Another difference between the United

States and developing countries is that water is actually treated. This refers to the fact that water is not drunk directly from the well. There are parameters set by government agencies that regulate the extent of how much arsenic is allowed to be present in the water. There are numerous techniques that water treatment faculties must use to control arsenic and other heavy metals. These corrosion control measures are not perfect and accidents do occur. Regardless citizens of developed countries have greater access to cleaner drinking water in comparison with their developing counterparts.

2.6 Vanadium:

Vanadium is a rare, soft, ductile gray-white element found combined in certain minerals and used to mainly to produce certain alloys (Water Treatment Solutions, 2016). Vanadium like the other heavy metals is used widely in industry. Vanadium can cause damage to DNA (Ehrlich, 2008) and DNA damage has been observed in other mammals such as rats (Sakurai, 1994).

The element vanadium is intriguing with an interesting history. When the metal was first discovered it was believed to chromium and not a new element. However, a few decades later it was confirmed that this element was a "new" element as was given the name of Vanadium.

> The chemical element vanadium was first discovered by Spanish-born Mexican mineralogist Andres Manuel del Rio, in 1801. He originally named the element "panchromum" because of the spectrum of colors associated with various oxides of the metal, but changed the name to "erythronium" because of the mineral salts turned red upon heating. Later, del Rio was convinced by scientists that he really found impure chromium and not a new element (Vanadium/Vanadyly, 2009).

The pure form of metallic vanadium does not exist in nature. However, vanadium is typically found in the various forms indicated below.

> The steel grey corrosion resistant metal exists in oxidation states from -1 to +5 but the most common valences are +3, +4, and +5 metallic vanadium does not occur in nature. The most stable oxidation state is the quadrivalent salts (Vo^2 vanadly) (Barcelox, 1999)

Vanadium has no biological importance. However, there may be a positive effect that the metals have for suffers of diabetes. This heavy metal is commonly beginning to be sold in a supplemental form for this reason. Supplements are not regulated in the same manner that drugs are. Therefore, based on current scientific data vanadium has not additional health benefits and is not seen as a trace metal. Like all other heavy metal vanadium is toxic.

As stated before it would appear that Vanadium has no biological importance. According a source reported in Clinical Toxicology; a vanadium-deficiency disease has not been defined in humans. Vanadium is a prime candidate for essential status in part, because vanadium occupies position 25 in the periodic table (Barceloux, 1999). There are several sources that states that a vanadium deficient diseases has not been identified. The status of vanadium as a trace metal is disputed. As of now there does not appear to be any biological function that this heavy metal plays. Even though Vanadium does not play a role in human biological functions. Vanadium is a heavy metal and can cause adverse health effects in humans.

Vanadium is widely used within industrial settings. The usefulness of vanadium was readily identified when the element was first discovered

> Use of vanadium include the following: (1) production of steel and nonferrous alloys, (2) catalyst for the production of sulfuric acid and for the conversion of naphthalene to phthalic andride, during the formation of plastic, (3) manufacturing of semiconductors, photo-graphic developers, and coloring agents, and (4) production of yellow pigments and ceramics (Bareceloux, 1999).

Apparently vanadium like copper and lead can leech into the water system via a method of corrosion. "Phosphate distribution system operators may be increasing V concentrations of treated water" (Gerke, 2010). This alludes to the complexity of water treatment chemistry. Phosphate additives are an effective way of controlling lead corrosion. However, there is a possibility that this same treatment is the cause of increased in V. However overall vanadium is not a problem in drinking water.

It is important to stress in some water systems using phosphate to control lead corrosion has led to increase levels of lead. Different water systems require different techniques. There may be other reasons why the corrosion techniques failed and they be indirectly related to the corrosion control techniques.

Unlike the three other heavy metals presented in this literature review. Vanadium is not presence in drinking. In the United States vanadium levels are monitored but overall it would appear not to be a problem on the same scale as lead and copper.

2.7 Recent Case Studies:

Throughout the recent modern era; occasionally there has been several heavy metal related disasters in regards to drinking water. Fortunately, with the following of proper scientific protocol which has developed several corrosion control techniques keep the situation under firm

control. An example of such a technique is othro-phosphate dosing. When this particular phosphate is added to the water it undergoes a chemical reaction which results in a scale forming inside the pipe. This protective scale covers the pipe and prevents lead from leeching into the drinking water system. However, each water source has its own unique water chemistry. Therefore, phosphate dosing may not be a viable solution at every location. In addition, phosphate dosing carries its own problems as well. Therefore, it is extremely important for water companies to conduct trail tests before making any permanent changes to their water chemistry.

These case studies were a general overview of two separate heavy metal contamination incidents involving lead. The first incident is the Washington D.C lead crisis which occurred around the year 2000. That particular lead crisis was a multi-year event which root cause was a change in water chemistry. The second incident is the current as of 2016, the Flint Michigan Lead Crisis. Unlike the Washington D.C event which lasted for several years. This crisis was discovered early after a few months. Like the Washington D.C incident this crisis was caused by a change in water chemistry.

The purpose of these case studies was to demonstrate the complexity of the water distribution and treatment network. In general water chemistry is an important concept to consider when treating water. A slight change in water chemistry could have disastrous consequences elsewhere in the distribution network. Water chemistry entails numerous parameters that ultimately depend on the source water. Therefore, no two water network has the same chemical makeup even if they come from the same source. Certain sources to have certain commonalities such as ground water tend to contain more hardness and typically come out of the ground clear and drinkable. However, there are differences among ground water source, so therefore a one size fits all treatment to water treatment is not advisable. Never the less with

proper testing of water chemistry before permanent changes are made could save time and money further down the line.

2.8 Washington D.C:

The Washington D.C lead toxicity crisis was seen as one of the largest lead related disasters of the modern era. This landmark event has shown the dangerous situation that numerous American cities are in. The crisis began roughly in the year 2000 when Washington D.C decided to implement chloramines as a disinfectant (Brown, 2006). Chloramines are used as an alternative to chlorine in certain water treatment processes. However as stressed in the preceding paragraph; any changes made to the water supply system should be thoroughly tested before permanent changes are implemented. If Washington D.C were to conduct a simple trail run, they may had discovered that chloramines have the added effect of changing the water chemistry. The change in the water chemistry by chloramines results in water that is much more corrosive. This corrosive water is able to strip lead from the pipes at an alarmingly high rate. The lead is now able to freely leech out into the water. During Washington's D.C lead crisis some homes lead levels were as high as 300 ppb (Guidotti, 2007). In addition, as of the year 2004 157 contained lead levels exceeding 300 part per billion and thousands more have exceeded the U.S EPA's 15-ppb action level (Renner, 2004). 300 parts per billion is nearly 20 times higher than the action level set by the EPA. At that level adverse health effects as noted in the lead subsection will occur, especially in children.

Washington D.C did attempt to correct the problem by using various corrosion control techniques such as phosphate dosing which probably should have been implemented from the beginning. They also in addition to implementing corrosion control techniques. D.C offered free blood testing, free lead filters and provided community outreach programs to educate the

community on issues regarding lead toxicity. Finally, Washington D.C decided to manually correct the problem by removing the lead branches and pipes throughout its water supply network. However, this has its own problems. First when the water leaves the treatment plant it is lead free. The leeched lead originates from the pipe network and the plumbing in the customers' homes. Washington D.C technically is not responsible for any lead containing materials on the customer's property. The customer themselves are fully responsible for removing all lead materials from their own property and bearing the financial burden. This is why lead toxicity and other heavy metal issues affect the poor more than anything else. Higher income residence can afford to remove lead containing materials from their properties. Unfortunately, lower income residences do not have this option. More government incentives are needed to be created to ensure a lead free future.

The primary lessons learned from the Washington D.C incident are that proper testing is crucial. The chloramines were used for a legitimate purpose. They reduce the dangerous organic by products associated with chlorine usage. However, chloramines slightly altered the water chemistry allowing lead to leech out into the water distribution network.

2.9 Flint Michigan:

The current lead related water crisis as of the year 2016 is in Flint Michigan. This crisis mirrors the Washington D.C crisis in regards that proper testing was not followed before changes were made to the water chemistry. In Flint Michigan the water source was originally Lake Michigan which is in general non-corrosive water. In order to save money, it was decided to switch the water source from Lake Michigan to the Flint River. However, no one decided to take any precautionary test to see what affects the new water will have on the distribution system. The water from the Flint River has an entirely different chemistry than that of lake water in general.

In reality the Flint River water is far more corrosive than the water from Lake Michigan. This oversight was not caught, therefore the much more corrosive water corroded the lead pipes and thus lead was able to leech out into the water supply network. According to the Flint Michigan report results of lead level test were found to be as high as 707 ug/L (Hyde, 2015).

Even before the toxic lead levels were discovered. Customers were complaining that the new water had a foul odor, stung when used as bathing water and tasted bad. This probably should have prompted someone in Flint Michigan to begin testing the water. Unlike the Washington D.C crisis which silently went on for years. The situation in Flint Michigan was discovered only about eight months after the switch to the new water source was made.

As of (Jan 2015) the city of Flint is under a state of emergency. The EPA has official stated to the residence of Flint Michigan to:

> EPA recommends that all residents use either bottled water or cold water that has been through a water filter certified to remove "total lead" for drinking, cooking and making baby formula until further notice. This is especially important for pregnant women, infants and children (Advice to Flint, 2015).

The lead levels were so high the water was dangerous to drink. This is why the EPA has taken the step to advise residences to either drink bottle water or use certify filters to remove lead from the water. In addition, a state of emergency has been declared in flint Michigan. Therefore, freeing additional resources so the people of Flint Michigan can receive the aide that they desperately need.

As with the Washington D.C incident; proper testing of the new water source would have alleviated the situation. The decision to change the water source was motivated by economic reasons. The irony is that now after the lead crisis occurred; the Flint Michigan water company

has implemented lead corrosion control in the form of phosphate dosing. The city could have saved money by testing the new water and implementing the proper lead corrosion controls. The damage has already been done. It takes at least several months for the effects of the phosphate dosing to take place. As stated before the phosphate dosing creates a scale which keeps the lead from leeching out of the water. Adding phosphate to the water in the present does not solve the situation currently.

In both situations the ultimately what was lost is the customer's trust within their respective water companies. Even though the politics of the situation will be ignored; the customer's trusted these companies to keep their water safe. Both companies were aware of the situation for an extended period of time before the crisis became public. Once trust has been lost it may never be recovered. Even if normalcy is restored; citizens will probably wonder if their water is safe to drink.

The positives of these crisis that lead in water are now receiving more attention. Furthermore, people are now paying attention to this fact as well. Therefore, perhaps there will be greater incentives for other water companies to avoid becoming the next Flint Michigan by taking proactive steps.

2.10 Water Treatment:

The water treatment process is a complicated economic endeavor. The water treatment process has many different variables depending on the local water condition. However, despite the regional differences the water treatment process follows a common set a processes. This section provides a general overview of the water treatment process. Each water company may have individualized water treatment procedures due to local water source differences.

The first step within the treatment process is the screening procedure. During this process larger objects are screened so that they cannot enter the facility. These objects include organic matter such as fish and other wildlife that is unfortunate to end up trapped. This process is executed because large objects can cause damage to the treatment plant. In addition, the screening process also protects the wildlife as well. The screens tend to be very well maintained and maintenance continuously. The screens are the first line of defense for any water treatment plant. If the screens were to fail it would wreak havoc on the treatment facility. Different water companies have different procedures but these screens are a commonality that the majority of all treatment plants share.

After the screening process has been completed and the large objects are removed. The next step in the treatment process; is the pre-sedimentation procedure. This procedure entails that the larger particles that were not removed during the screen phase are allowed to settle at the bottom of the tank. This leads to the following stage known as coagulation. Coagulation refers to the adding of any chemical that induces a positive charge negating negative particle charges. The negation of the positive charges allows the smaller particles to clump together, forming larger particles. These larger particles are easier to remove. As indicated before each water treatment facility has their own coagulation agent depending on the local water chemistry. For example, Washington D.C coagulation process as follows:

> A coagulant (Aluminum Sulfate) is added to the water as it flows to sedimentation basins coagulants aid the removal of suspended particles in the water causing them to consolidate and settle (Hickey, 2008).

The coagulation agent does have an impact on water chemistry. Depending on the local water conditions. The particle agent that will be used is usually tested to ensure that there will not be any adverse effects.

While the water is undergoing the coagulation process the water undergoes flocculation. The water is slowly stirred. After this process is completed the water enters the sedimentation phase and the particles settle to the bottom of the tank. This is where the majority of all suspended particles settle.

The next steps are filtration and disinfection. The remaining particles are removed during the filtration phase. Under the disinfection process chlorine, chloramines, and sometimes ammonia is added. Lastly fluoride is added. After fluoride is added the water is ready to drink

2.11 Corrosion Control:

Corrosion control or corrosion inhibitors are crucial techniques in any water supply network. Corrosion inhibitors inhibit the amount of corrosion within the distribution network. There are several common corrosion control techniques such as orthophosphate, polyphosphate and sodium hex. These corrosion inhibitors operate in a similar manner; a scale is form which controls the amount of corrosion. Each corrosion inhibitor requires different water chemistry. Therefore, each corrosion control used must be tailored to each water network.

The next steps are filtration and disinfection. The remaining particles are removed during the filtration phase. Under the disinfection process chlorine, chloramines, and sometimes ammonia is added. Lastly fluoride is added. After fluoride is added the water is ready to drink.

3.1 Chapter Three Methodology:

The First step was to identify sources of excessive lead levels in residential households within the defined study area. This was accomplished by utilizing data provided by the water company within this city. The high lead levels are identified with run charts and the problematic locations are revealed by use of the Pareto Chart. Measure lead in relation and contrast with the maximum threshold lead limit of 15 ppb as defined by the EPA's lead and copper rule of 1992. Determine if this process was capable. The data was analyzed using statistical process control specifically; capability index to derive a statistical conclusion to determine if this process was under control and capable. This statistical analysis was performed by the MINITAB software. Data was provided by the water company from a city in the Midwest in an excel spreadsheet. A sample data is shown in Table 1 below.

Table 1: Modified Data from Anonymous Water Company

	DATE SAMPLED	Sample Location	2015 R2 (ppb)	2015 R1 (ppb)	2014 R2 (ppb)	2014 R1 (ppb)	2013 R2 (ppb)	2013 R1 (ppb)	2012 R2 (ppb)	2012 R1 (ppb)	2011 R2 (ppb)	2011 R1 (ppb)
1	8/27/2015	A	5.38	5.57	3.20	2.62	2.02	2.07	1.58	2.41	2.88	1.3
2	8/27/2015	B	2.91	0	2.53	2.53	1.88	0	2.87	3.09	1.76	19
3	9/4/2015	C	10	2.13	2.74	1.36	1.5	1.5	2.33	1.62	5.44	3
4	9/21/2015	D	1.91	1.38	2.57	1.28	1.9	0	2.44	1.46	3.04	2.2
5	8/28/2015	E	2.49	0	1.16	1.03	2.01	0	1.15	0	2.13	0
6	8/28/2015	F	10.1	7.21	16.2	3.52	3.11	1.3	3.97	0	2.15	1.2
7	8/28/2015	G	7.13	1.51	11.3	2.31	2.04	2.04	3.17	1.49	4.95	3.5
8	9/1/2015	H	2.85	1.64	2.26	1.04	2.14	2.14	8.06	3.21	9.03	11.3
9	8/30/2015	I	28.9	17.2	39.2	73.2	23.4	23.4	27.1	14	7.5	13.5
10	8/25/2015	J	2.93	2.03	4.66	2.59	1.78	2.54	1.36	0	0	0
11	9/2/2015	K	7.05	0	0	1.16	1.25	0	1.5	2.2	1.92	1.7
12	9/9/2015	L	38.3	7.3	31.4	4.65	19.5	19.5	12.3	20.7	27.2	20.9
13	8/28/2015	M	9.66	4.71	7.48	3.28	5.79	2.72	7.94	3.1	6.53	4.3
14	9/21/2015	N	2.09	1.34	4.51	1.68	5.04	1.28	3.28	1.93	2.45	5.4
15	9/3/2015	O	3.63	2.11	2.46	3.48	1.14	1.14	2.84	2.05	1.05	2
16	8/25/2015	P	4.03	0	3.86	1.87	4.51	2.23	4.92	3.48	6.55	4.2
17	9/2/2015	Q	2.49	0	1.71	0	1.11	0	2.93	0	1.54	1.9
18	8/30/2015	R	7.3	3.69	11.5	3.14	3.88	3.88	5.74	4.24	4.25	3.1
19	9/20/2015	S	3.05	2.45	1.76	1.94	3.5	1.3	2.37	1.28	2.4	1.1
20	9/29/2015	T	6.23	4.11	8.35	3.44	4.42	1.44	4.4	1.55	3.5	5.8

A more completed chart from which the data was derived from is located within the appendix. However, the data set is extremely large therefore the completed data set lacks copper samples. In addition, it only contains samples from the years 2015-2011.

The following are the three main objectives of the methodology.

1. Identify sources of excessive lead levels in residential households within the defined study area. This was accomplished by utilizing data provided by the water company within this city. The high lead levels are identified with run charts and the problematic locations are revealed by use of the Pareto Chart.

2. Measure lead in relation and contrast with the maximum threshold lead limit of 15 ppb as defined by the EPA's lead and copper rule of 1992. This process was carried out by using MS Excel table and run charts.

3. Determine if this process was capable. The data was analyzed using statistical process control specifically; capability index to derive a statistical conclusion to determine if this process was under control and capable. This statistical analysis was performed by the MINITAB software.

Excel and Minitab both have their own strengths and weakness regards to statistical analysis. Constructing run charts is a simpler task within excel. However, the Pareto charts, control charts even though these charts can be created within Excel MINITAB handles these tasks better. Finally, statistical process control analysis can be done manually within excel but MINITAB handles these process automatically.

4.1 Chapter Four Data Analysis and Conclusion

4.2 Data Analysis of Objective One:

Table 2: Modified Data from Anonymous Water Company

	DATE SAMPLED	Sample Location	2015 R2 (ppb)	2015 R1 (ppb)	2014 R2 (ppb)	2014 R1 (ppb)	2013 R2 (ppb)	2013 R1 (ppb)	2012 R2 (ppb)	2012 R1 (ppb)	2011 R2 (ppb)	2011 R1 (ppb)
1	8/27/2015	A	5.38	5.57	3.20	2.62	2.02	2.07	1.58	2.41	2.88	1.3
2	8/27/2015	B	2.91	0	2.53	2.53	1.88	0	2.87	3.09	1.76	19
3	9/4/2015	C	10	2.13	2.74	1.36	1.5	1.5	2.33	1.62	5.44	3
4	9/21/2015	D	1.91	1.38	2.57	1.28	1.9	0	2.44	1.46	3.04	2.2
5	8/28/2015	E	2.49	0	1.16	1.03	2.01	0	1.15	0	2.13	0
6	8/28/2015	F	10.1	7.21	16.2	3.52	3.11	1.3	3.97	0	2.15	1.2
7	8/28/2015	G	7.13	1.51	11.3	2.31	2.04	2.04	3.17	1.49	4.95	3.5
8	9/1/2015	H	2.85	1.64	2.26	1.04	2.14	2.14	8.06	3.21	9.03	11.3
9	8/30/2015	I	28.9	17.2	39.2	73.2	23.4	23.4	27.1	14	7.5	13.5
10	8/25/2015	J	2.93	2.03	4.66	2.59	1.78	2.54	1.36	0	0	0
11	9/2/2015	K	7.05	0	0	1.16	1.25	0	1.5	2.2	1.92	1.7
12	9/9/2015	L	38.3	7.3	31.4	4.65	19.5	19.5	12.3	20.7	27.2	20.9
13	8/28/2015	M	9.66	4.71	7.48	3.28	5.79	2.72	7.94	3.1	6.53	4.3
14	9/21/2015	N	2.09	1.34	4.51	1.68	5.04	1.28	3.28	1.93	2.45	5.4
15	9/3/2015	O	3.63	2.11	2.46	3.48	1.14	1.14	2.84	2.05	1.05	2
16	8/25/2015	P	4.03	0	3.86	1.87	4.51	2.23	4.92	3.48	6.55	4.2
17	9/2/2015	Q	2.49	0	1.71	0	1.11	0	2.93	0	1.54	1.9
18	8/30/2015	R	7.3	3.69	11.5	3.14	3.88	3.88	5.74	4.24	4.25	3.1
19	9/20/2015	S	3.05	2.45	1.76	1.94	3.5	1.3	2.37	1.28	2.4	1.1
20	9/29/2015	T	6.23	4.11	8.35	3.44	4.42	1.44	4.4	1.55	3.5	5.8

This modified chart provided by the water company forms the formation of the statistical analysis of this thesis. The data shows twenty anonymous locations and their lead levels from the years 2011 to 2015. During each year lead samples are collected at each location twice. Hence the rounds. Round one (R1) is collected during the first half of the year. Round two (R2) are samples collected during the second half of the year.

The locations above the 15 ppb as defined by the EPA are during round one F for the year the year 2014, I 2012-2015, and L 2011-2015. For round two the locations above the 15 ppb action level are B for 2011, I 2011-2015 and L 2011. This is indicated within the two graphs below.

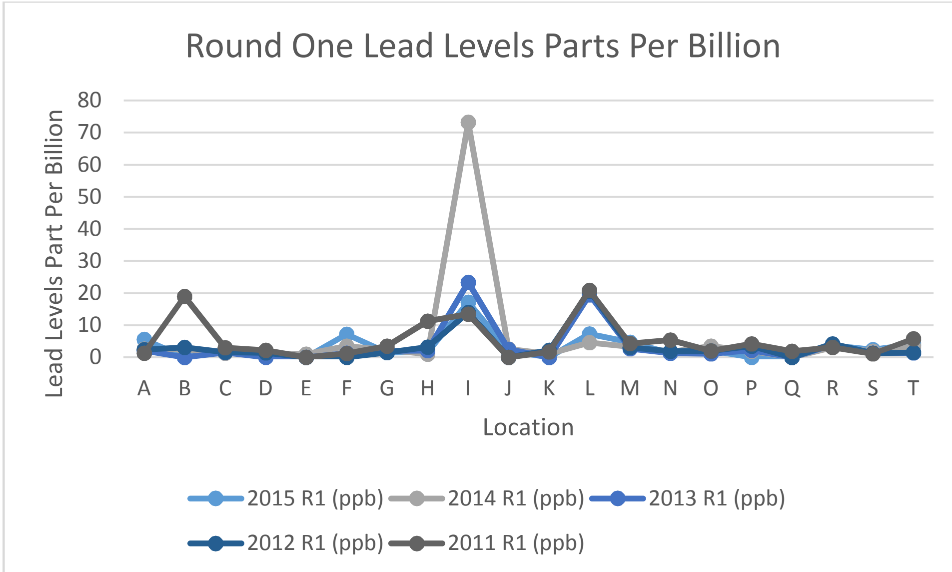

Figure 1: Run Chart Round One Lead Levels

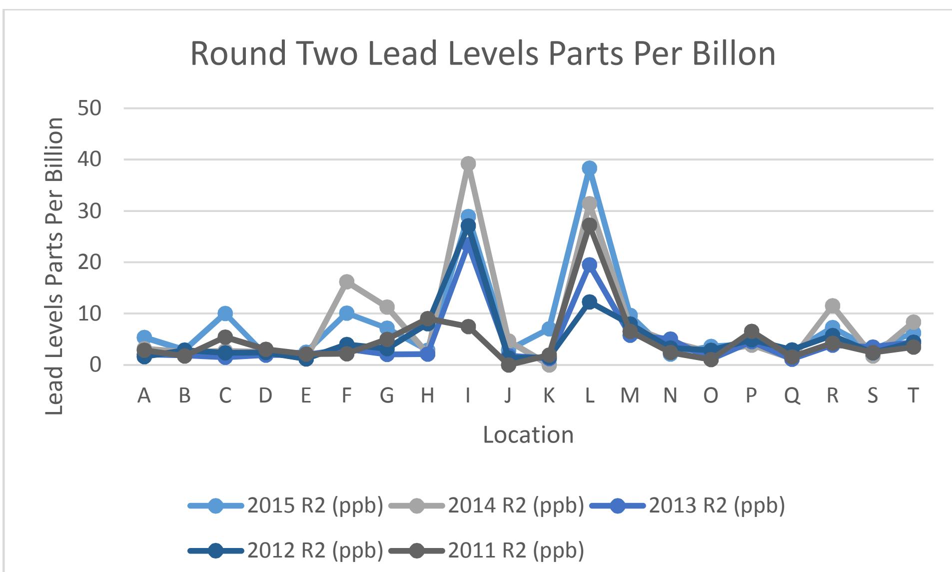

Figure 2: Run Chart Rounds Two

The follow graph is a Pareto graph. This graph is able to ascertain the problematic locations.

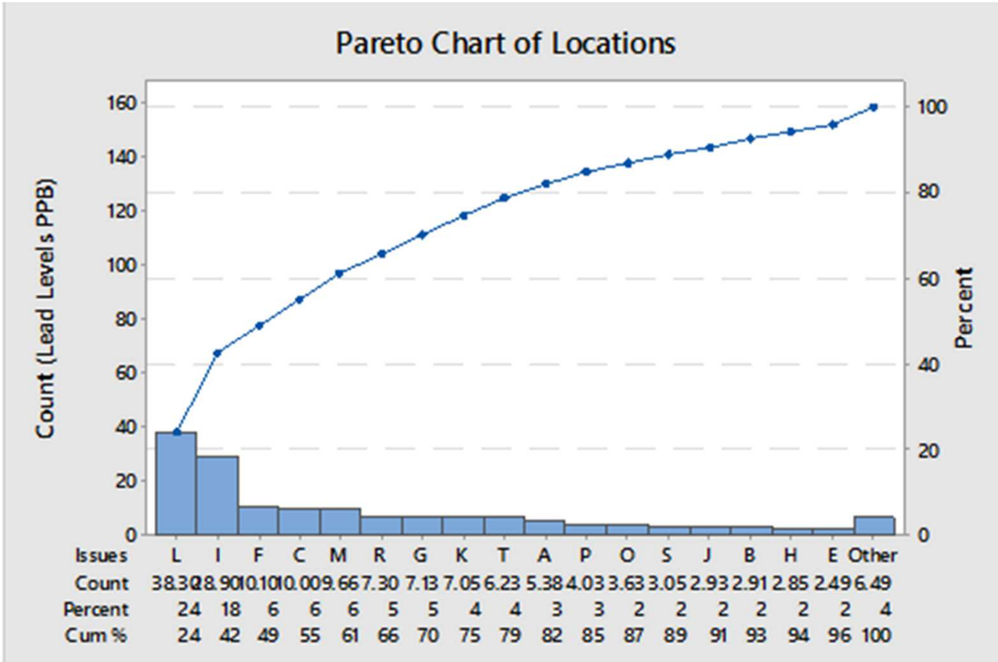

Figure 3: Pareto Chart of Locations

According to this Pareto chart within this process locations L and I are responsible for 80% of the high lead values. This corresponds with the two run charts which visualizes locations L and I have abnormally high lead levels.

The Pareto chart was chosen because Pareto Charts can indirectly confirm the results of run charts and control charts. The locations I and L are responsible for the majority of the lead values within this process. This refers to the high lead levels seen at these locations in the run charts within the previous sections. In addition, these are the two locations that are out of the specification range as seen in the control chart in figure six. The inference which can be obtained from the Pareto chart is that these two locations should be examined closely. By solving the issue of high lead levels within these locations; should solve the high lead problems within the entire process.

4.3 Data Analysis of Objective Two:

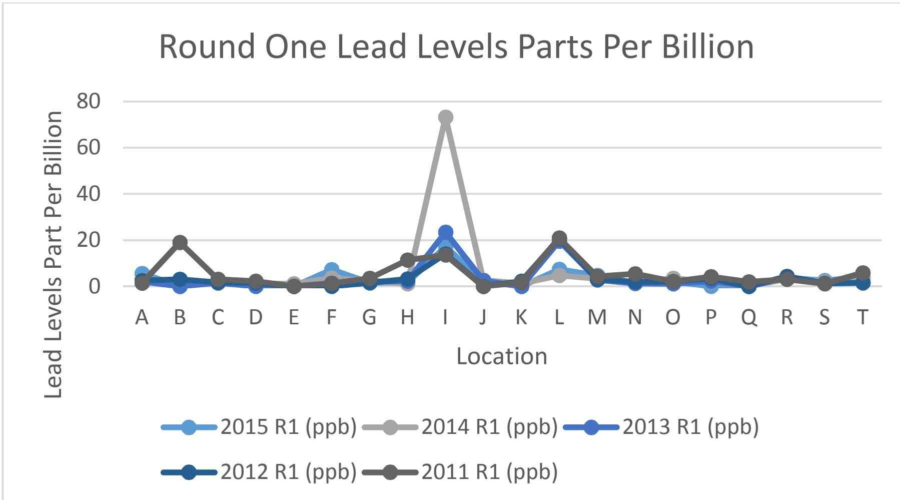

Figure 4: Run Chart Round One

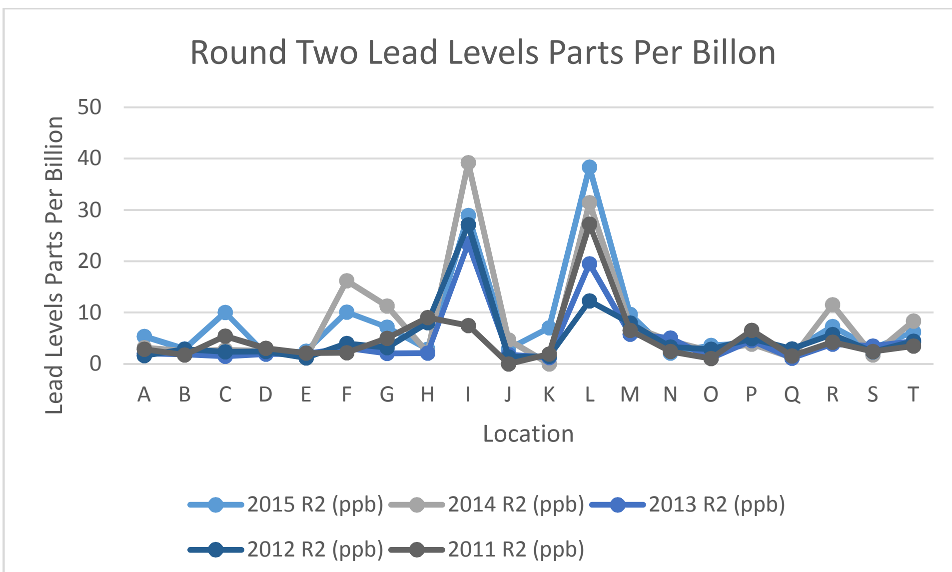

Figure 5: Run Chart Round Two

These two run charts correspond with the Pareto chart. Locations I and L have extremely high lead values. According to the Pareto chart locations I and L are responsible for 80% of the problems within this process. According to the source whom provided the data set. These two

locations historically have low usage, and their location does not allow proper scale formation. As indicated in the literature review low usage can inversely lead to higher lead readings.

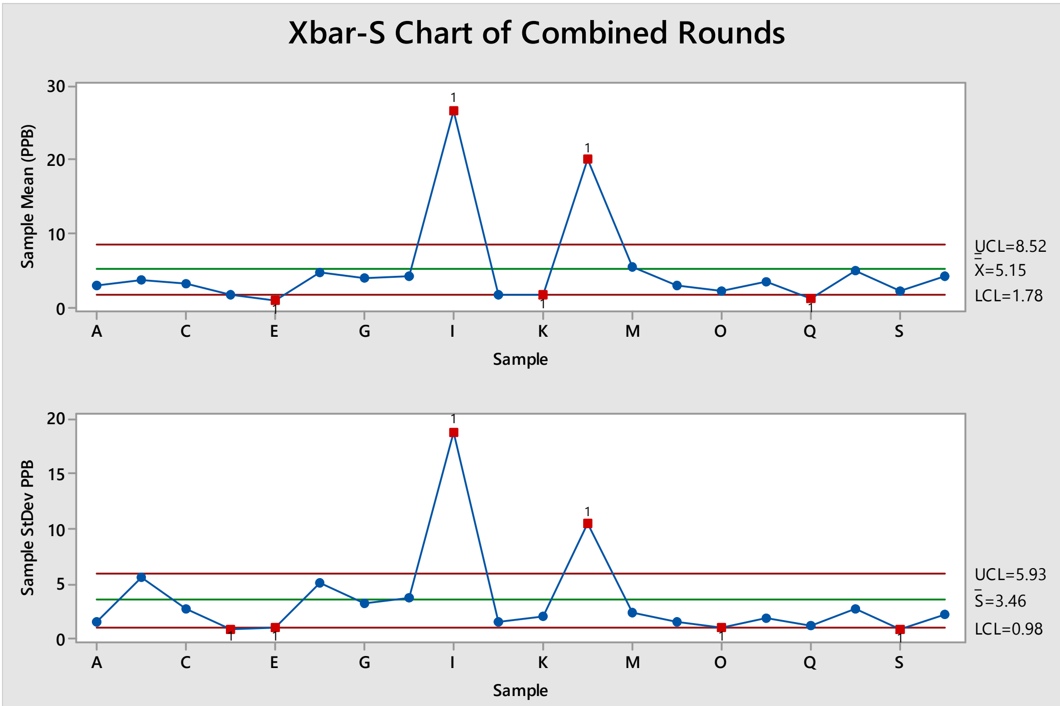

Figure 6: Control Chart of Combined Rounds

The control chart above indicates that locations I and L are out of the specification range. The lower out of specification range locations are ignored because low lead values are positive. I and L locations out of specification corresponds with both the control charts and the Pareto chart. Detail reason why these locations are out of control was provided in the previous section. These locations have low water usage and their locations do not promote scale formation.

4.4 Data Analysis of Objective Three: Process Capability

Process capability refers to a series of statistical analysis that can determine if a process is under statistical control. In the context of this thesis only Process Capability which is also known

as C_P determines if the process is capable. The second value is Process Capability Index (C_{PK}) which determines if the process is centered.

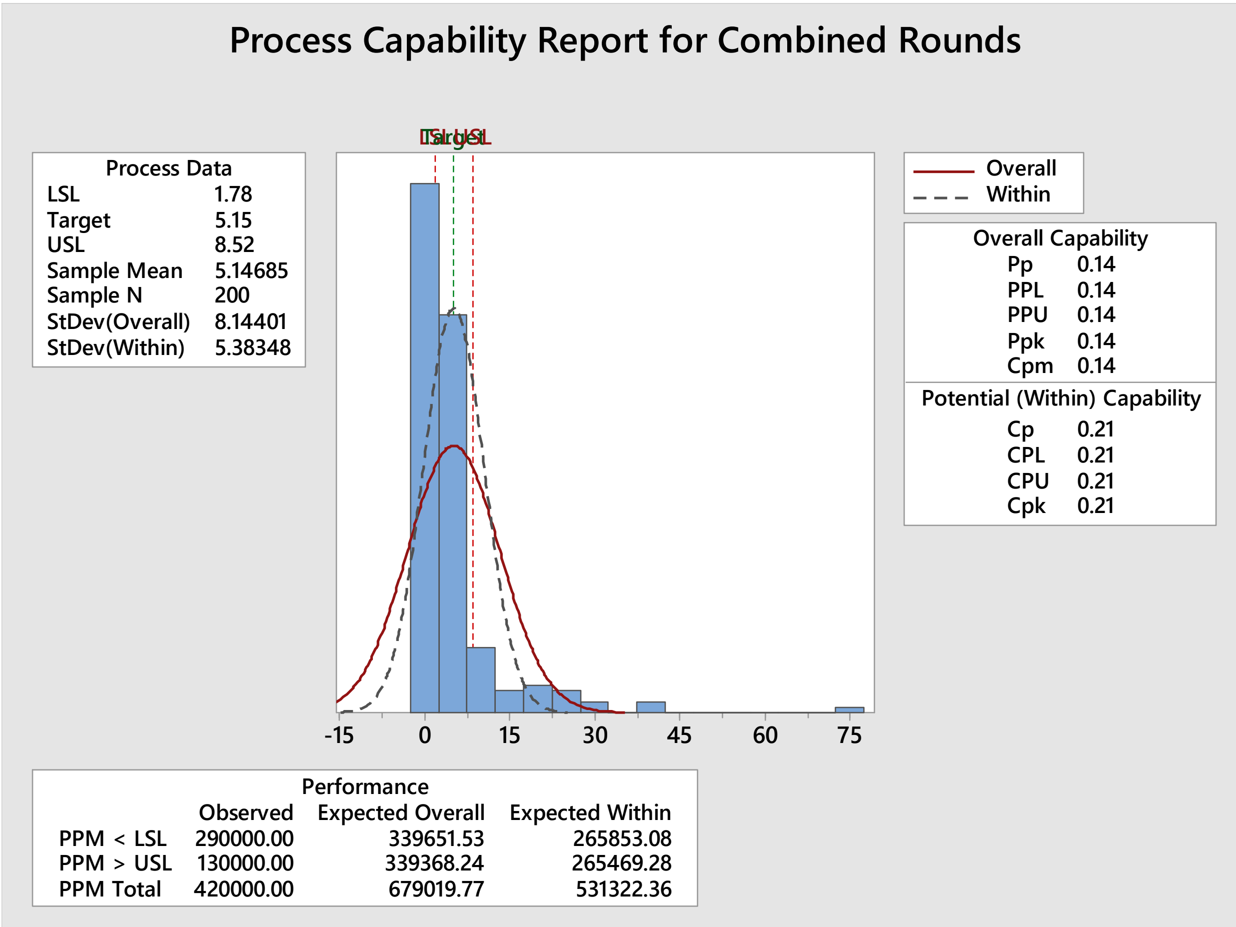

Figure 7: Process Capability Report for Combined Rounds

Utilizing the information provided in the control chart in the previous sub section. This process capability analysis was constructed in Minitab. $C_{PK}= C_P$ with a value of .21 which indicates that this process is center, however the values are below 1 which indicated this process was not capable. Under this particular statistical analysis, a C_{PK} and C_P less than one means that this particular process is not under statistical control and is not capable.

However standard statistical process control techniques allow for out of specification points to be removed. The control chart below represents points I and L removed.

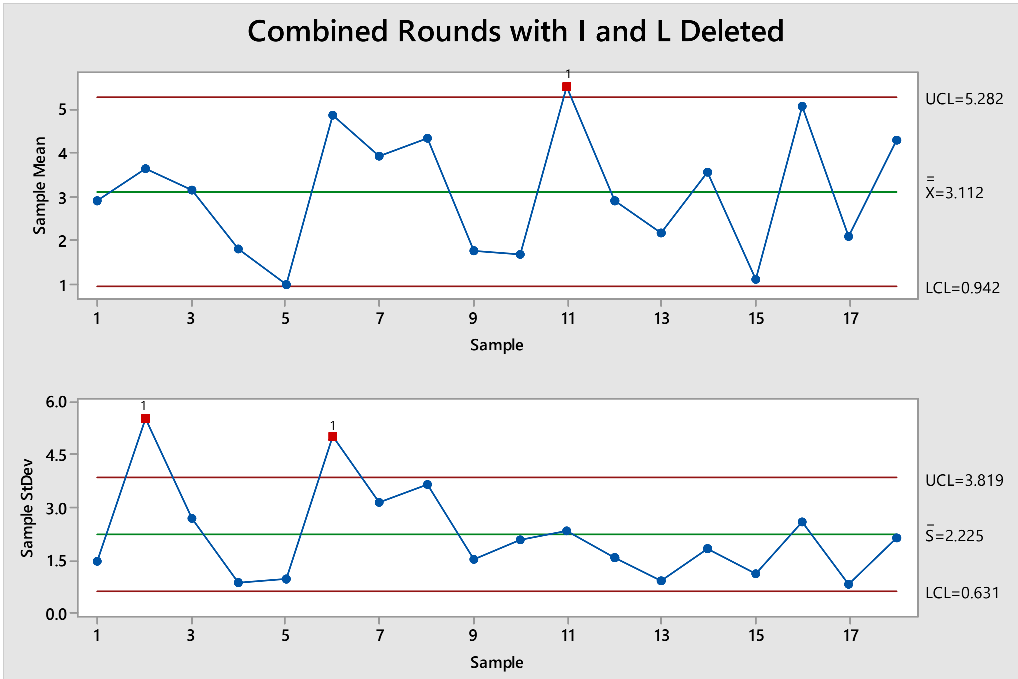

Figure 8: Control Chart of I and L Deleted

Under the revision points M is the sole out of specification item. Since the control chart was revised the process capability analysis was revised as well.

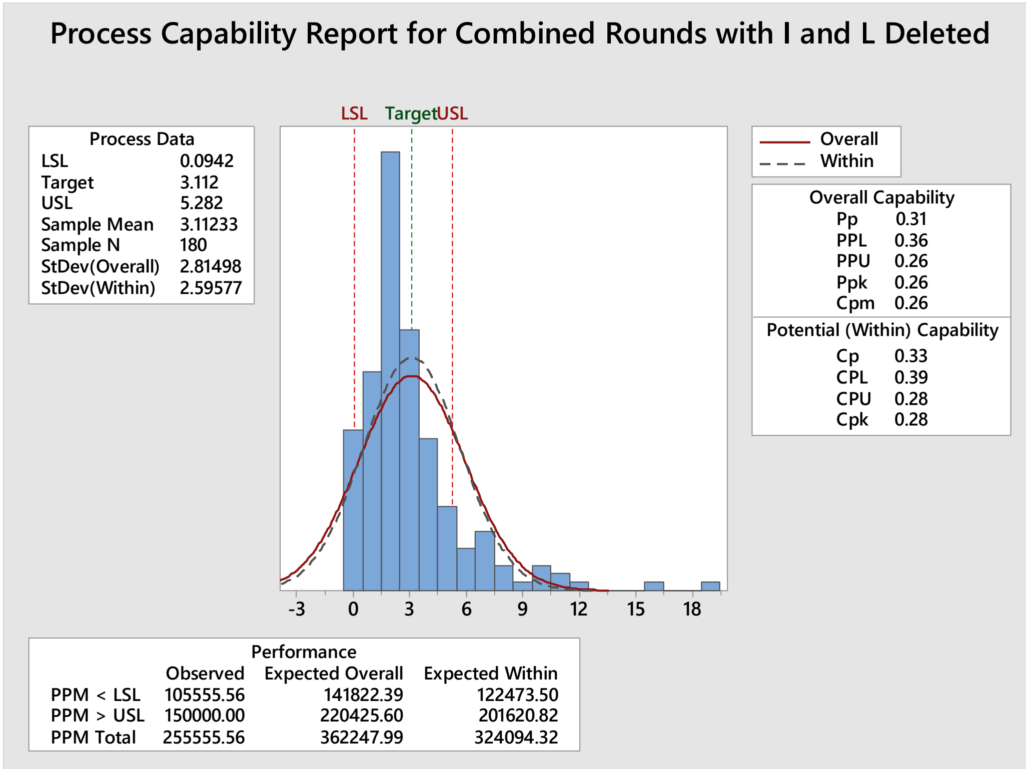

Figure 9: Process Capability Report for Combined Rounds with I and L Deleted

Under the second process capability analysis the process was not capable. C_{PK} and C_P are less than one. However, C_P does not equal C_{PK} which would indicate that this process is still not centered. The last out of specification point has been removed and the final control chart has been constructed below.

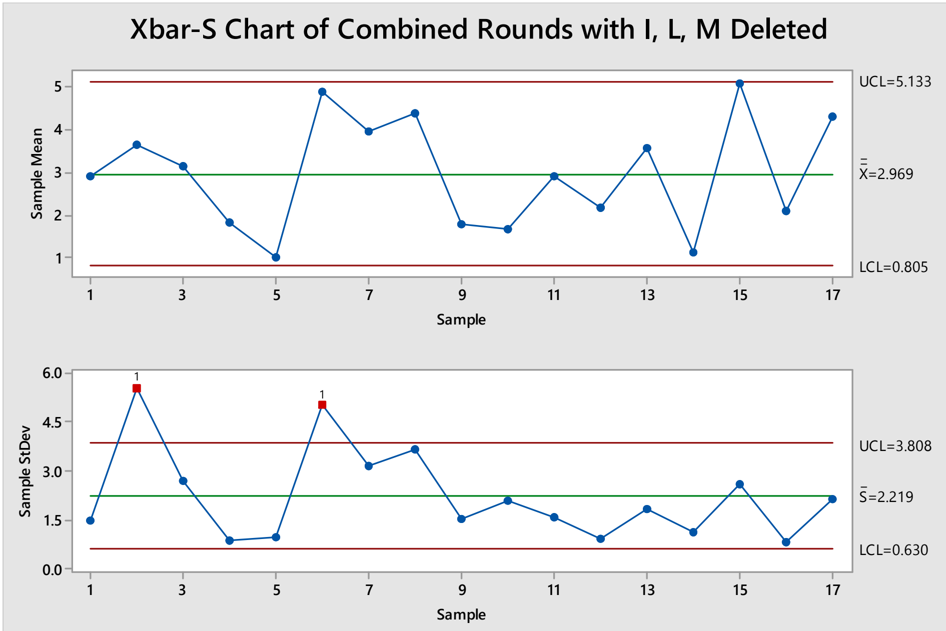

Figure 10: Control Chart of Combined Rounds with I, L, M Deleted

With M deleted all points are under control. The final process capability analysis was listed below.

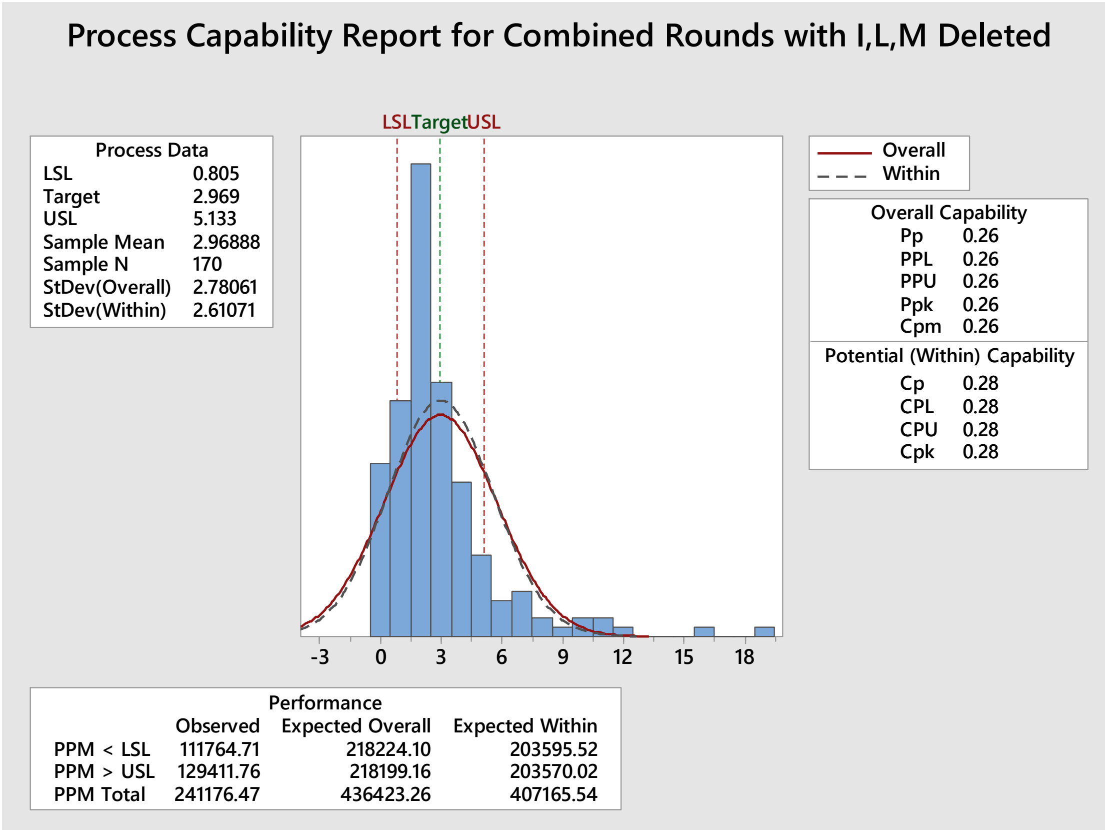

Figure 11: Process Capability Report of Combined Rounds with I, L, M Deleted

As with the first process capability analysis C_{PK} equals C_P which means this process is centered. However, the values are still less than one which would have indicated this process was not capable.

4.5 Discussion of Findings:

Overall the process is not capable. The process capability analysis always produces C_{PK} and C_P values less than one, which under this form of analysis indicates that this particular process is not under statistical control. This does not imply that there is a problem with lead quality within this Midwestern city. According to the EPA this city is in full compliance. This would imply that statistical process control may not appropriate for this type of analysis.

However, the information provided within this thesis would be useful in situations where a company may want to determine which locations should receive the most attention.

The reason why the SPC analysis results with the EPA's results is that these two analysis are different. The EPA is only interested in households with lead levels greater than 15 ppb calculated to the 90th percentile. The 90th percentile allows for a few households to exceed the action level. SPC is a different form of analysis which examines if this process can be continued successfully. From an SPC stand point this process will never be stable. As part of the conclusion SPC may not be appropriate for this form of analysis.

However, quality control techniques mandate that root cause of problem are identified. Locations I and L have abnormally high lead values. The reasons, specifically for the high lead values is due to these locations historically low water usage and improper scale formation due to geography. Locations with low water usages will by default have higher lead values as discussed with in the literature review. Locations far from the treatment facility the solution which would promote scale formation may dissipate. The advantage with using manufacturing techniques to investigate environmental concerns is that it promotes root cause analysis.

4.6 Conclusion:

Even though the analysis proved that the process was not capable, this thesis does show that utilizing process capable for environmental purposes may not be ideal. However, the basic tools of quality such as Pareto Chart and control charts are easily applicable to environmental topics.

The final conclusion of this thesis is that process capability analysis may not be appropriate for environmental issues. That statically procedure was develop to assist within

manufacturing processes. Manufacturing processes can largely be modified and change. The environment or rather the lead samples cannot easily be modified. The lack of modification makes process capability problematic. The results in addition conflicts with the EPA's own guideline. This Midwestern city is within full compliance of the lead and copper rule. However, according to the process capability conducted within this thesis, the process was not capable and needs further revision.

Even though process capability cannot be readily applied to environmental concerns. Other aspects of quality analysis such as the tools of quality can be applied as demonstrated by this thesis. Pareto charts are effective in showing areas of concern. While controls charts are able to verify information present within the Pareto chart. Therefore, the aspect of root analysis can somewhat be applied to environmental concerns.

4.7 Recommendation:

The recommendation for this Midwestern city is to address the two locations within the Pareto chart. Those two locations represent 80% of the problems in this process. Due to legalities of water industry; even though direct action would be difficult. Never the less perhaps maybe an attempt to change the laws that would allow water companies to take direct control of all water related material in regardless of their location would be ideal.

The overall process can be utilized in other locations as a form of root cause analysis. The water companies themselves must follow the EPA's own guidelines. However, the control charts, run charts, and Pareto Chart and other forms of water analysis can assist with root cause analysis. For example, the run chart, control and Pareto Chart within this thesis was able to show

the problematic locations. At this point root cause analysis was performed to find the issue at these locations.

With the Pareto chart revealing the problematic locations and root cause analysis discovering the reasons for the high lead levels. Perhaps this particular water company could promote higher water usage at these locations. In addition, a new technique should be developed to promote scale formation at these locations. As the research indicates lead at any level is toxic for human health. Therefore, it is vital that any and every steps are taken to protect the health of the citizens.

4.8 References:

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Appendix

Tables 1 & 2: Modified Data from Anonymous Water Company

	DATE SAMPLED	Sample Location	2015 R2 (ppb)	2015 R1 (ppb)	2014 R2 (ppb)	2014 R1 (ppb)	2013 R2 (ppb)	2013 R1 (ppb)	2012 R2 (ppb)	2012 R1 (ppb)	2011 R2 (ppb)	2011 R1 (ppb)
1	8/27/2015	A	5.38	5.57	3.20	2.62	2.02	2.07	1.58	2.41	2.88	1.3
2	8/27/2015	B	2.91	0	2.53	2.53	1.88	0	2.87	3.09	1.76	19
3	9/4/2015	C	10	2.13	2.74	1.36	1.5	1.5	2.33	1.62	5.44	3
4	9/21/2015	D	1.91	1.38	2.57	1.28	1.9	0	2.44	1.46	3.04	2.2
5	8/28/2015	E	2.49	0	1.16	1.03	2.01	0	1.15	0	2.13	0
6	8/28/2015	F	10.1	7.21	16.2	3.52	3.11	1.3	3.97	0	2.15	1.2
7	8/28/2015	G	7.13	1.51	11.3	2.31	2.04	2.04	3.17	1.49	4.95	3.5
8	9/1/2015	H	2.85	1.64	2.26	1.04	2.14	2.14	8.06	3.21	9.03	11.3
9	8/30/2015	J	28.9	17.2	39.2	73.2	23.4	23.4	27.1	14	7.5	13.5
10	8/25/2015	K	2.93	2.03	4.66	2.59	1.78	2.54	1.36	0	0	0
11	9/2/2015	L	7.05	0	0	1.16	1.25	0	1.5	2.2	1.92	1.7
12	9/9/2015	M	38.3	7.3	31.4	4.65	19.5	19.5	12.3	20.7	27.2	20.9
13	8/28/2015	N	9.66	4.71	7.48	3.28	5.79	2.72	7.94	3.1	6.53	4.3
14	9/21/2015	O	2.09	1.34	4.51	1.68	5.04	1.28	3.28	1.93	2.45	5.4
15	9/3/2015	P	3.63	2.11	2.46	3.48	1.14	1.14	2.84	2.05	1.05	2
16	8/25/2015	Q	4.03	0	3.86	1.87	4.51	2.23	4.92	3.48	6.55	4.2
17	9/2/2015	R	2.49	0	1.71	0	1.11	0	2.93	0	1.54	1.9
18	8/30/2015	S	7.3	3.69	11.5	3.14	3.88	3.88	5.74	4.24	4.25	3.1
19	9/20/2015	T	3.05	2.45	1.76	1.94	3.5	1.3	2.37	1.28	2.4	1.1
20	9/29/2015	U	6.23	4.11	8.35	3.44	4.42	1.44	4.4	1.55	3.5	5.8

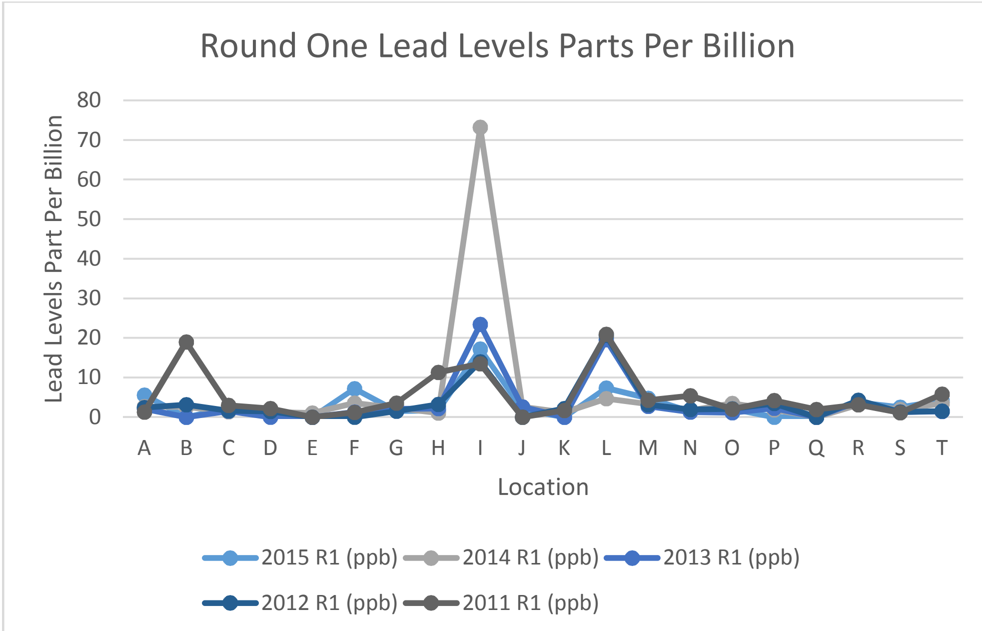

Figure 1 & 4: Round One Run Chart

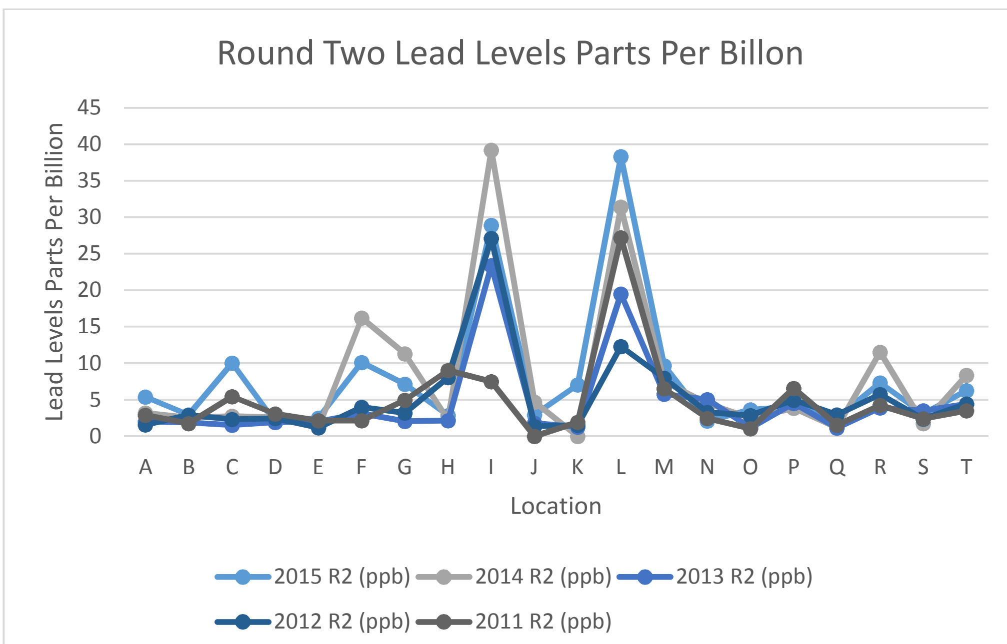

Figure 2 & 5: Round Two Run Chart

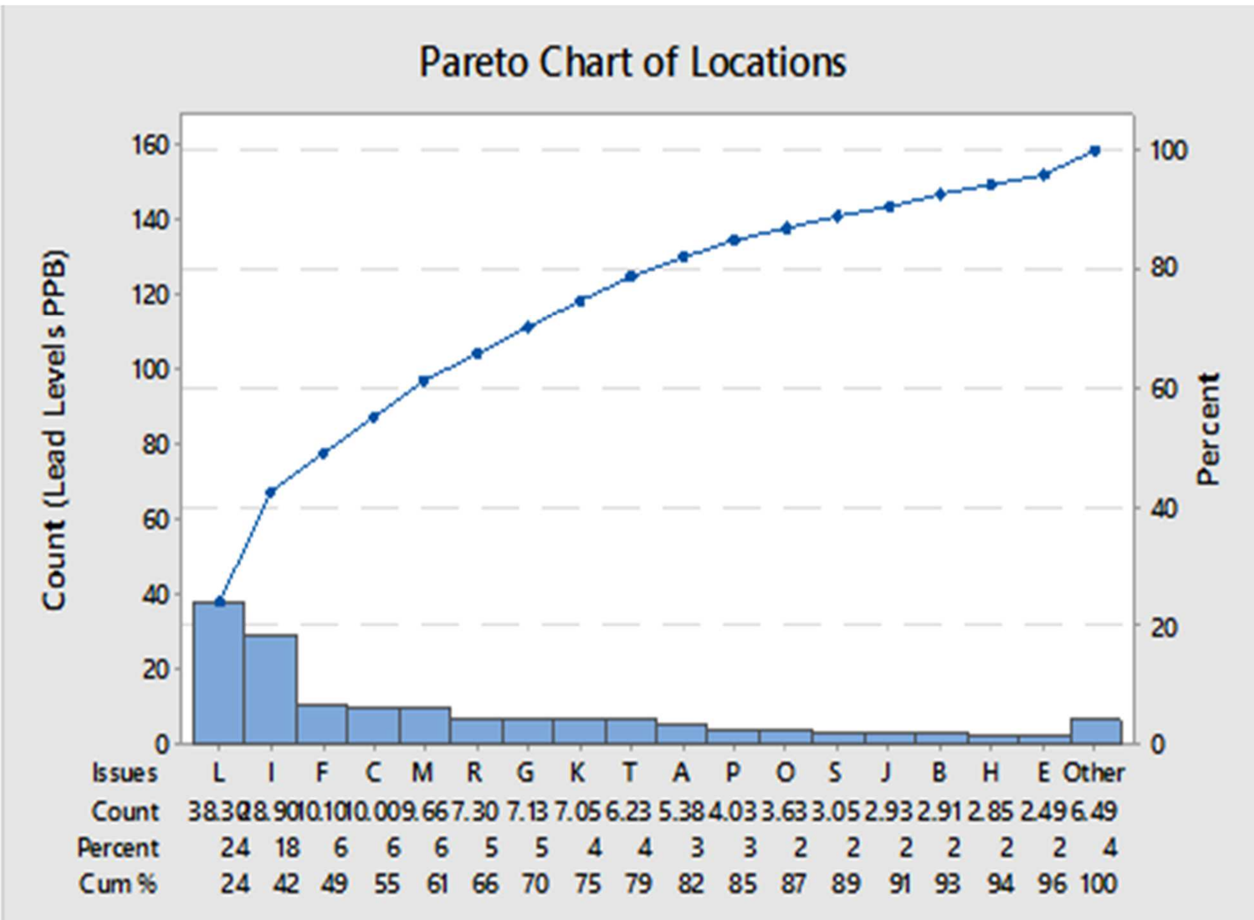

Figure 3: Pareto Chart of Locations

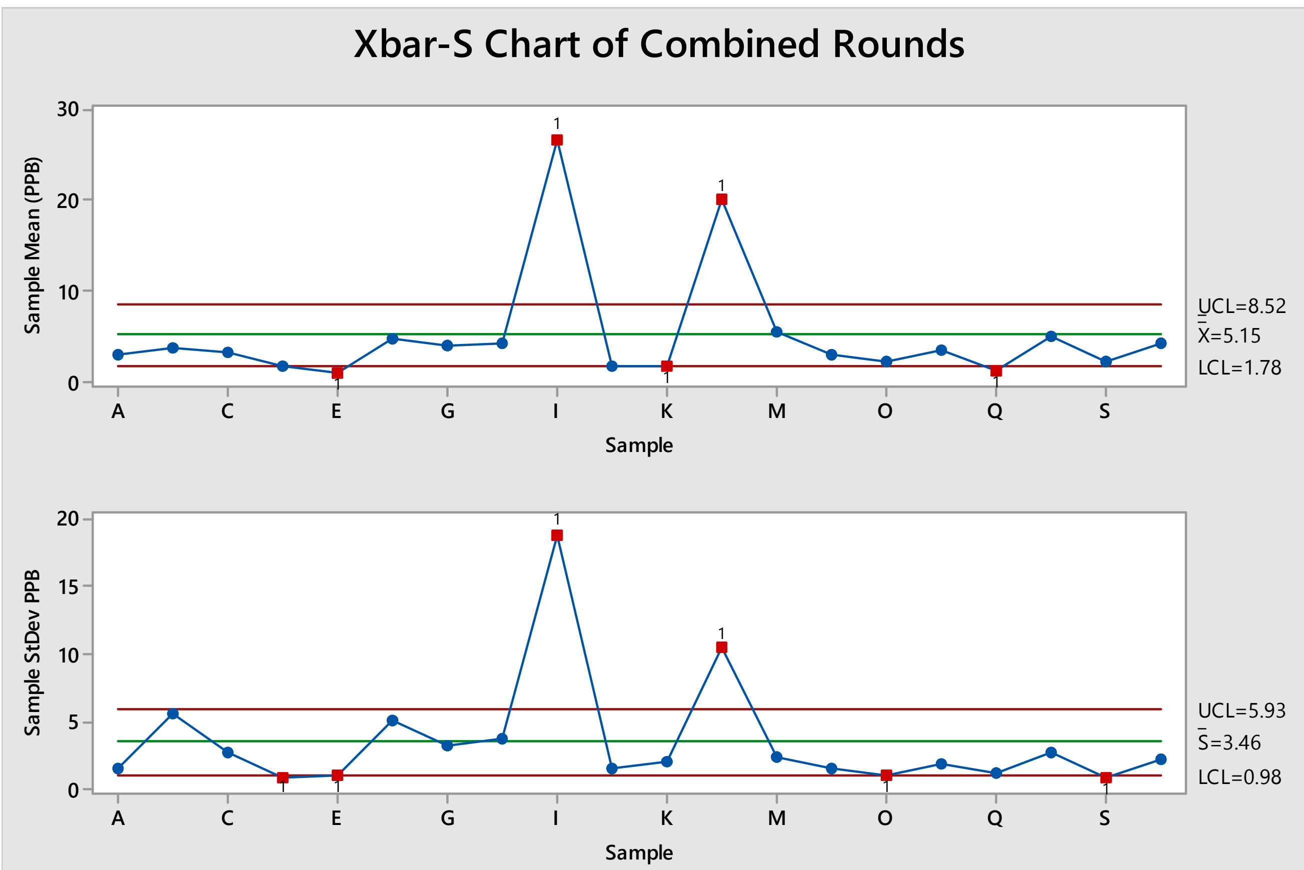

Figure 6: Control Chart of Combined Rounds

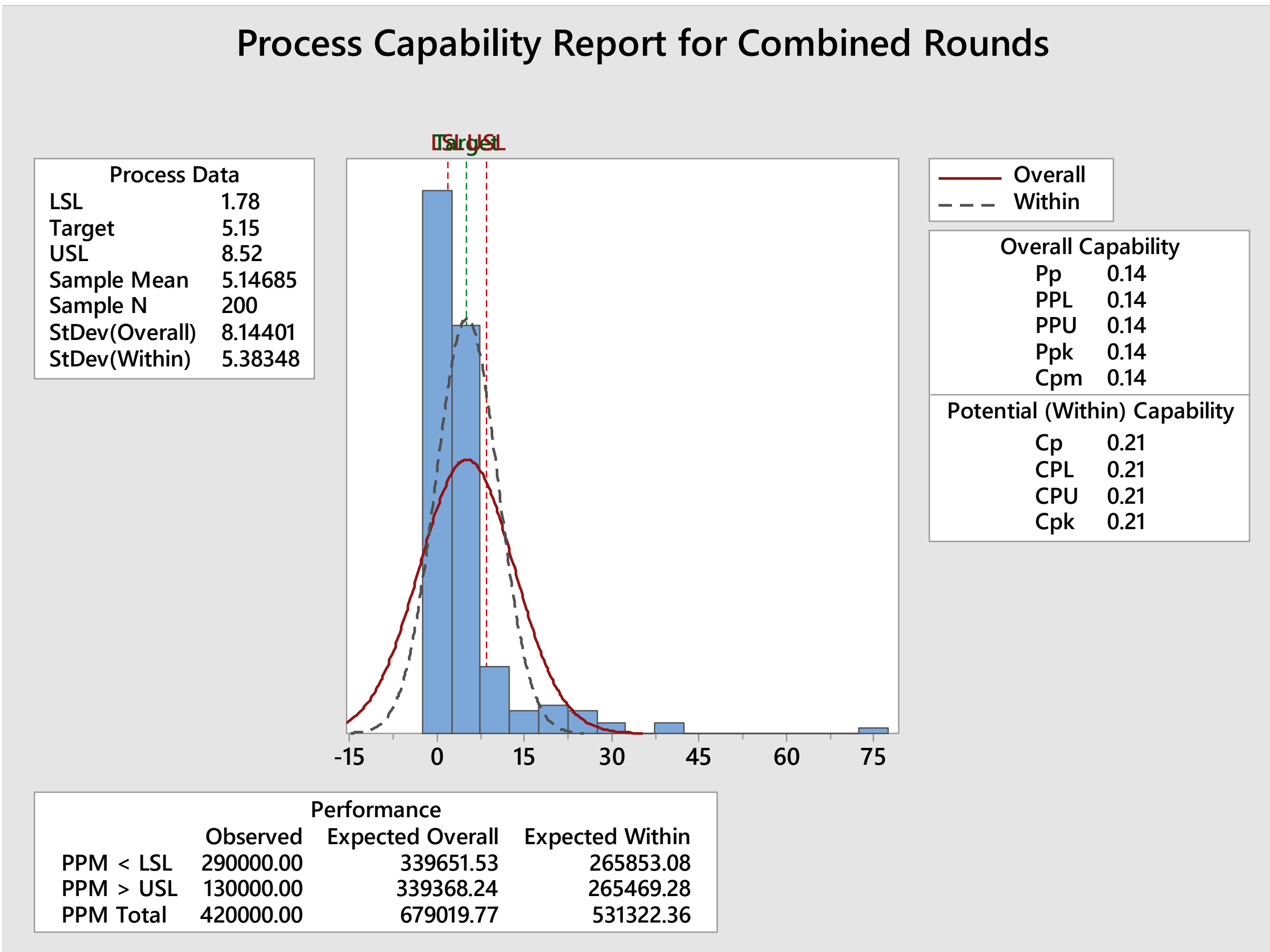

Figure 7: Process Capability Report for Combined Rounds

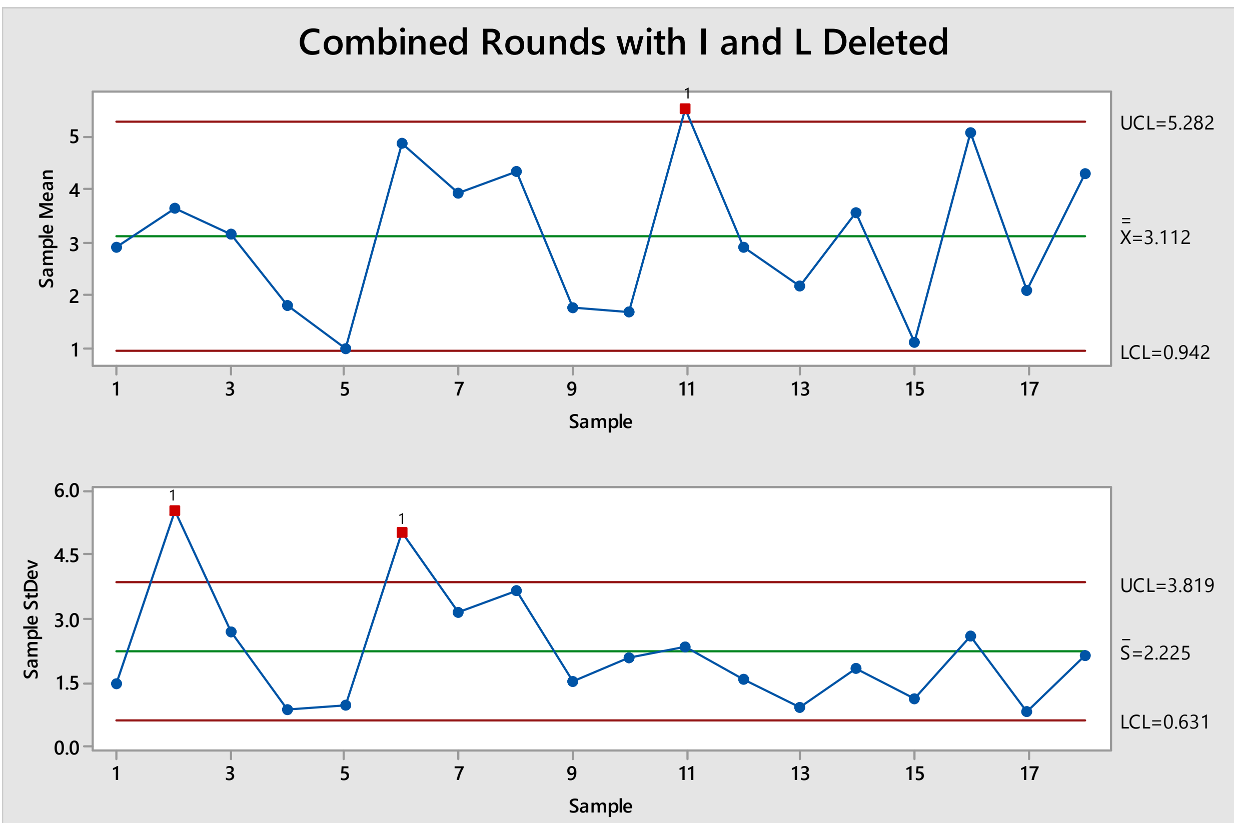

Figure 8: Control Chart of I and L Deleted

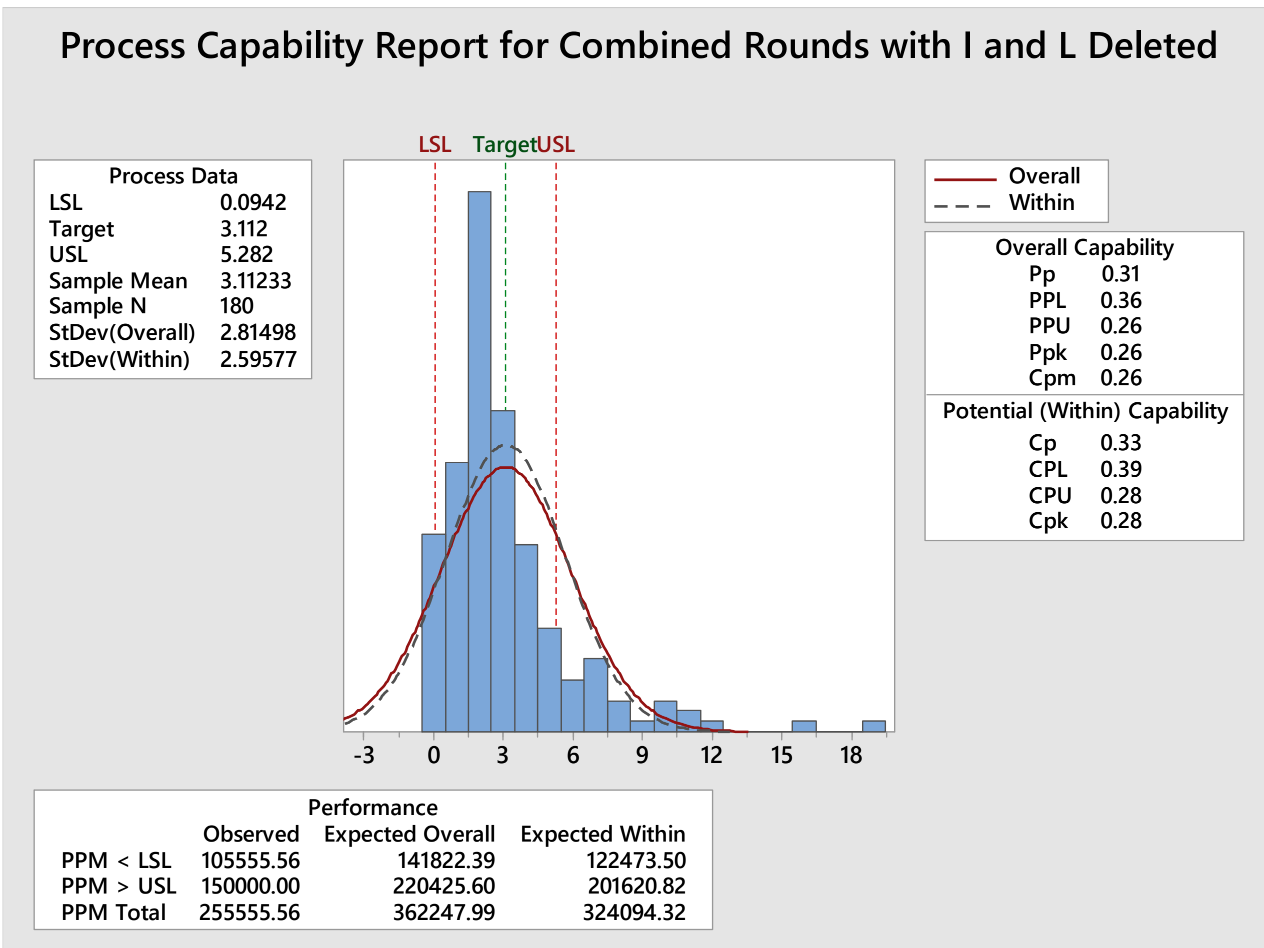

Figure 9: Process Capability Report for Combined Rounds with I and L Deleted

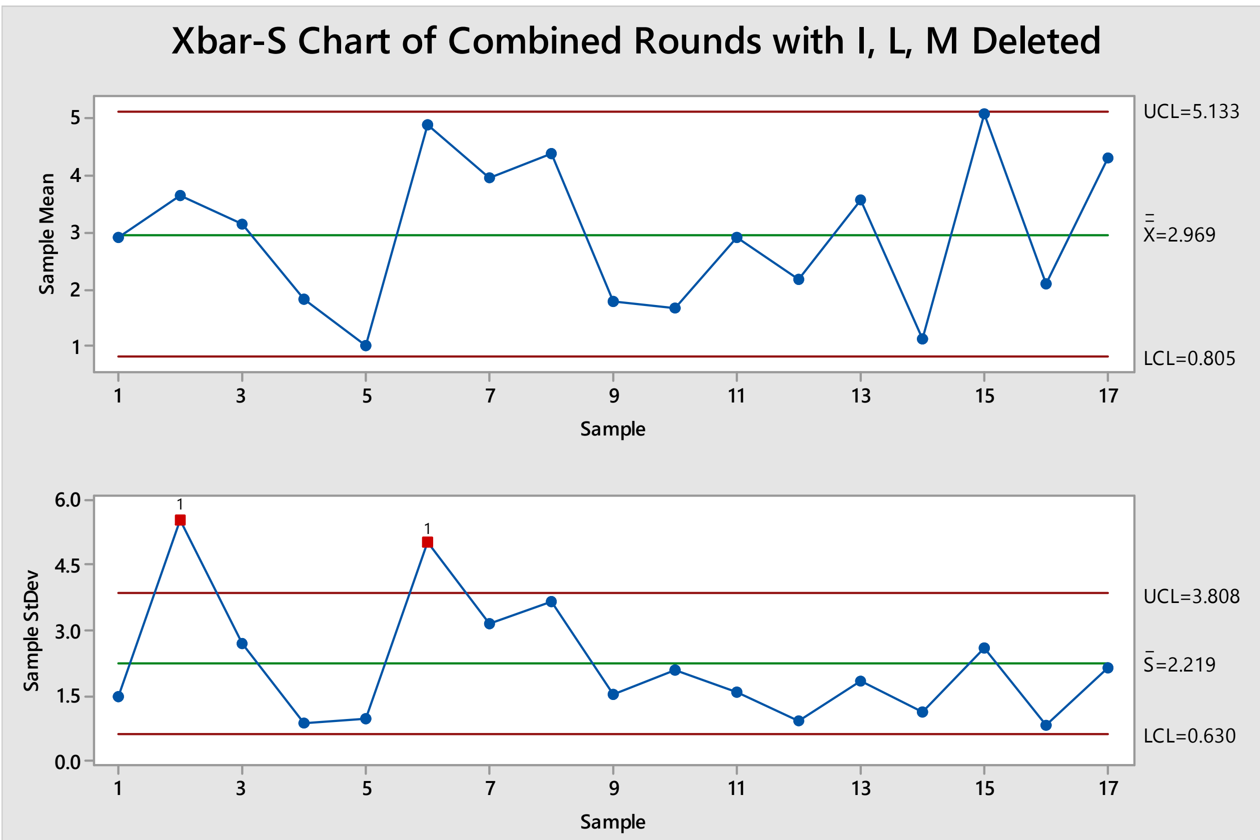

Figure 10: Control Chart of Combined Rounds with I, L, M Deleted

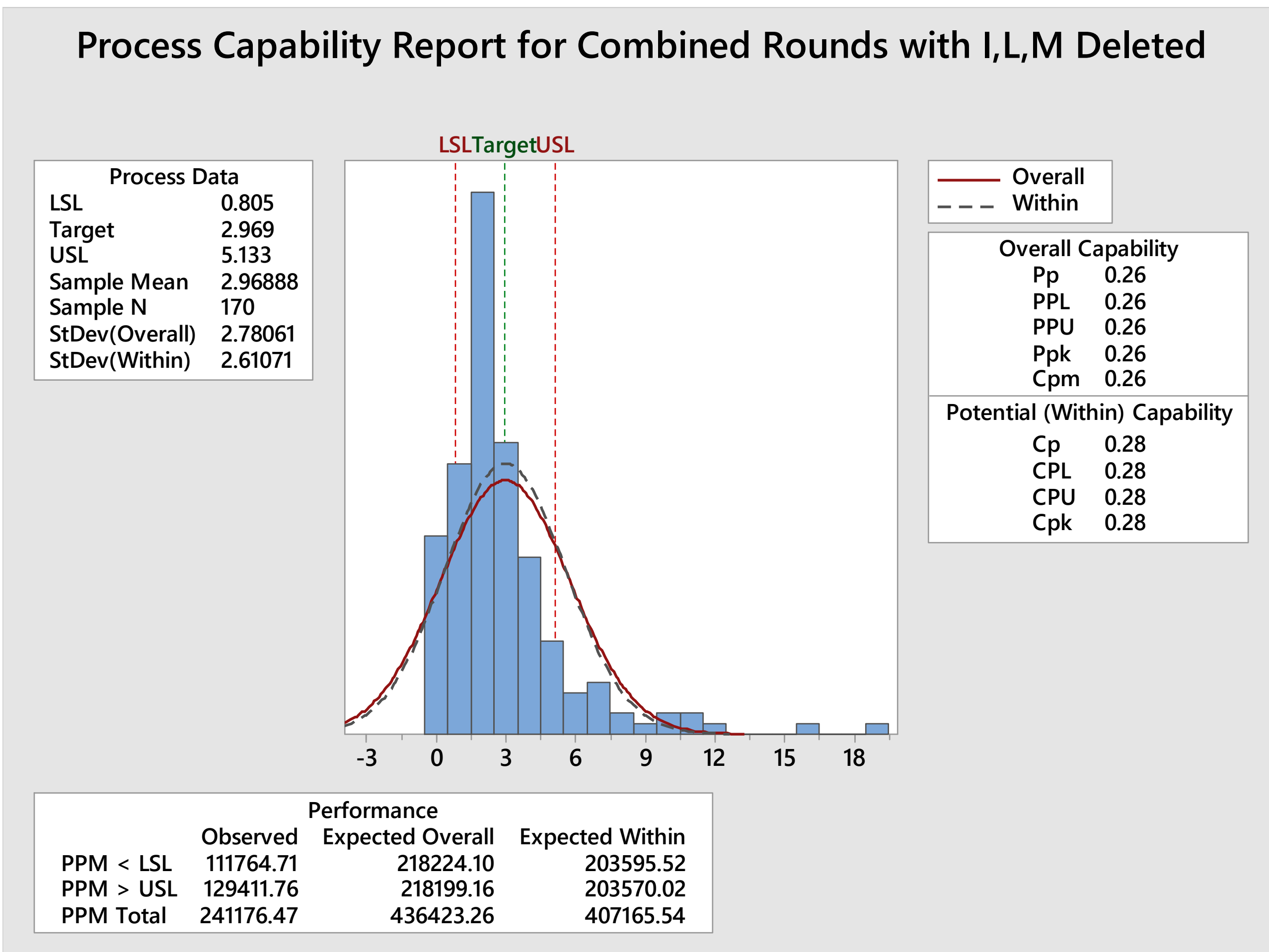

Figure 11: Process Capability Report of Combined Rounds with I, L, M Deleted

Table 3: Contain Modified lead data which contains all lead data form year 2011 copper data hidden.

Service Line	DATE KIT SENT	DATE SAMPLED	2015 R2 Pb Results	2015 R1 Pb Results	2014 R2 Pb Results	2014 R1 Pb Results	2013 R2 Pb Results	2013 R1 Pb Results	2012 R2 Pb Results	2012 R1 Pb Results	2011 R2 Pb Results	2011 R1 Pb Results
Pb			0		0		0		0		0	0
Pb	08/24/15	8/27/2015	5.38	5.57	3.20	2.62	2.02	2.07	1.58	2.41	2.88	1.3
Pb	08/24/15	10/6/2015	1.6	1.24	7.79							
Pb	08/24/15	8/29/2015	1.58	0	0	1.14	0	0	0	0	0	0
Pb	08/24/15	9/1/2015	43.9									
Pb	08/24/15	8/31/2015	1.72	0	0	0	0	0	2	0	1.15	0
Pb	08/24/15	8/27/2015	2.91	0	2.53		1.88	0	2.87	3.09	1.76	19
Pb	08/24/15	10/1/2015	51.1									
Pb	08/24/15	8/30/2015	1.87	0	0	0	0	0	0	0	0	0
Pb	08/24/15	9/4/2015	10	2.13	2.74	1.36		1.5	2.33	1.62	5.44	3
Pb	08/24/15	9/21/2015	1.91	1.38	2.57	1.28	1.9	0	2.44	1.46	3.04	2.2
Pb	08/24/15	8/29/2015	2.14	1.16	4.60	1.6						
Pb	08/24/15	8/31/2015	1.59	0	1.08	0						
Cu	08/24/15	9/3/2015	1.43	0	0	0	0	0	0	0	0	0
Pb	08/24/15	9/2/2015	1.58	0	0	0		1.43	0	0	0	0
Pb	08/24/15	9/2/2015	1.45	0	0	0	0	0	0	0	0	0
Pb	08/24/15	8/28/2015	2.49	0	1.16	1.03	2.01	0	1.15	0	2.13	0
Pb	08/24/15	8/28/2015	10.1	7.21	16.2	3.52	3.11	1.3	3.97	0	2.15	1.2
Pb	08/24/15	8/28/2015	1.34	0	0	0	0	0	0	0	0	0
Pb	08/24/15	9/3/2015	1.69	1.15	0	0		0	0	0	0	0
Pb	08/24/15	8/28/2015	7.13	1.51	11.3	2.31		2.04	3.17	1.49	4.95	3.5
Pb	08/24/15	8/29/2015	1.32	0	0	0	0	0	0	0	1	0
Pb	08/24/15	9/1/2015	2.85	1.64	2.26	1.04		2.14	8.06	3.21	9.03	11.3
Pb	08/24/15	8/26/2015	21.6									
Pb	08/24/15	8/31/2015	5.19	0	4.28	0	3.1	0	1.57	0	1.43	0
Pb	08/24/15	8/30/2015	28.9	17.2	39.2	73.2	23.4		27.1	14	7.5	13.5
Pb	08/24/15	8/25/2015	1.51	0	0			0	0	0	0	0
Pb	08/24/15	8/25/2015	2.93	2.03	4.66	2.59	1.78	2.54	1.36	0	0	0
Pb	08/24/15	9/2/2015	7.05	0	0	1.16	1.25	0	1.5	2.2	1.92	1.7

Pb	08/24/15	9/9/2015	38.3	7.3	31.4	4.65		19.5	12.3	20.7	27.2	20.9
Pb	08/24/15	8/28/2015	2.12	0	0	0	1	0	0	0	0	0
Pb	08/24/15	8/28/2015	9.66	4.71	7.48	3.28	5.79	2.72	7.94	3.1	6.53	4.3
Pb	08/24/15	9/21/2015	2.09	1.34	4.51	1.68	5.04	1.28	3.28	1.93	2.45	5.4
Pb	08/24/15	10/1/2015	0	0	0	0		0	0	0	0	0
Pb	08/24/15	9/3/2015	3.63	2.11	2.46	3.48		1.14	2.84	2.05	1.05	2
Pb	08/24/15	9/25/2015	8.13	1.02	1.61							
Pb	08/24/15	8/25/2015	4.03	0	3.86	1.87	4.51	2.23	4.92	3.48	6.55	4.2
Pb	08/24/15	9/2/2015	2.49	0	1.71	0	1.11	0	2.93	0	1.54	1.9
Pb	08/24/15		0	0								
Pb	08/24/15	8/30/2015	7.3	3.69	11.5	3.14	3.88	3.88	5.74	4.24	4.25	3.1
Pb	08/24/15	9/20/2015	3.05	2.45	1.76	1.94	3.5	1.3	2.37	1.28	2.4	1.1
Pb	08/24/15	9/29/2015	6.23	4.11	8.35	3.44	4.42	1.44	4.4	1.55	3.5	5.8
Pb	08/24/15	9/26/2015	0	1.08	2.78	0	0					
Pb	08/24/15	10/2/2015	2.36	2.14	2.92	3.59	7.25					
Pb	08/24/15	9/26/2015	0	0	0	4.78	0	0	0	0	0	0
Pb	08/24/15	9/20/2015	0	0	0	0	0	0	0	0	0	0
Pb	08/24/15	10/12/2015	1.09	0	1.34	0	5.94	0	0	0	2.15	1.4